FEDERAL ECOLOGICAL MONITORING PROGRAM

Summary Report

Environment Canada L'environnement Canada

Fisheries and Oceans Pêches et Océans

PREFACE

This report presents the highlights of the Federal Ecological Monitoring Program (FEMP) Final Report, a 2-volume, 10-chapter report that documents FEMP's background, objectives, methods, results, conclusions, and recommendations. The interested reader is referred to the FEMP Final Report for a more comprehensive treatment of the topics highlighted here.

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INTRODUCTION

In 1986, the Department of the Environment (DOE) and the Department of Fisheries and Oceans (DFO) began a joint, five-year program of environmental research and monitoring in northern Manitoba, called the Federal Ecological Monitoring Program (FEMP). FEMP was an investigation of the environmental impacts of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project. This report: 1) describes the circumstances that lead to the initiation of FEMP; 2) explains FEMP's purpose and objectives; and 3) summarizes FEMP's conclusions and recommendations.

BACKGROUND

The LWCN project is located in the boreal forest area of northern Manitoba, an area rich in natural resources: fish and wildlife; forests; minerals; and enormous hydroelectricity potential. It is a large, remote area with a harsh climate, consisting of long, cold winters and short, cool summers. Population in the LWCN project area is limited to a few resource-based communities and six native communities. Thompson, the largest community, is a mining and service center with a population of 15 000. The six native communities of South Indian Lake, Nelson House, Cross Lake, Norway House, Split Lake, and York Landing have a total population of approximately 14 000.

Occupancy of this region by the predecessors of the residents of the native communities dates back thousands of years. Wage labour and a stratified occupational hierarchy have been facts of economic life in these communities for at least two centuries. Although neither wage employment nor the market system are foreign to these communities, there is typically a substantial level of economic activity that takes place outside of the market sphere. This resource-based subsistence activity does not constitute a separate and distinct economy but rather is inextricably linked with wage labour and transfer payments.

The subsistence economy (i.e. the domestic harvesting of fish, waterfowl, fur bearers, moose and other game, berries and medicinal plants) is as fundamental to the support of the communities' culture and social relations as it is to their economic structure. Extensive and intensive use of their often large resource areas (e.g. the South Indian Lake registered trapline section is approximately 35,000 km^2) continues to take place and to contribute to the communities' cultural and economic well-being. In this sense, these "communities" extend well beyond their permanent settlements.

Because subsistence harvest activity is not simply an addition to available income but, rather, is inherent to the maintenance of social relations, subsistence-based economies may be affected by industrial development in a way which is fundamental, not peripheral, to their functioning. Changes in the location, abundance and quality of water-dependant resources such as fish, aquatic fur bearers, and waterfowl can affect patterns of community land use and the viability and success of resource harvesting efforts.

The water regime of this area was changed dramatically by the LWCN project. This hydroelectric development involves: 1) the regulation of Lake Winnipeg by means of a number of control structures in the Outlet Lakes area, such as 2-Mile Channel between Lake Winnipeg and Playgreen Lake, 8-Mile Channel between Playgreen Lake and Kiskittogisu Lake, and Jenpeg Dam located upstream of Cross Lake; 2) the diversion of most of the Churchill River at Southern Indian Lake (SIL) into the headwaters of the Rat River and from there into the Burntwood and Nelson rivers; and 3) the construction of a planned total of nine dams on the Nelson River and four along the Churchill River Diversion (CRD) route. To date five dams have been built on the Nelson River: Jenpeg, Kettle, Kelsey, Long Spruce, and Limestone. Currently, approval is being sought to build a sixth dam at Conawapa. Only a control structure has been built to date on the CRD - at Notigi, to control outflows from SIL. It is anticipated that the first dam on the CRD, to be commenced after Conawapa, will be at Wuskwatim Lake. Construction of the LWCN project began in the early 1970s and is expected to continue well into the next century.

WHAT WAS FEMP?

In 1977, the landmark Northern Flood Agreement (NFA) was signed by Canada, Manitoba, Manitoba Hydro and the Northern Flood Committee (NFC) - an organization representing five of the six native communities in the LWCN project area. (South Indian Lake, located on provincial crown land, is not a reserve and is not a member of the NFC.) The objective of the NFA, an open-ended, open-funded, legally binding contract, is to ensure that all persons represented by the NFC who are adversely affected by the LWCN project receive fair and equitable treatment. Under the terms of the NFA, the NFC filed Claim 18, in 1981, alleging that the other 3 parties to the NFA had failed to meet certain contractual obligations of the NFA, including a failure to implement a long-term coordinated ecological monitoring and research program that would allow evaluation of impacts on the communities. This claim was the impetus for FEMP.

FEMP, therefore, was a partial fulfilment of Canada's obligations under a legal contract, a sharp contrast to most government environmental programs that are implemented as a result of legislation or government policy. The NFA is, however, a difficult agreement to interpret and implement because of its complexity, breadth of scope, and the imprecision of many of its clauses (e.g. "eradicate mass unemployment and poverty").

In September 1986, a four-party Program Advisory Board (PAB) was established to coordinate the ecological monitoring and research programs being conducted in response to Claim 18. During its time, PAB was unique in that it was the only established mechanism for four-party dialogue on any of the NFA provisions. FEMP's objectives, and the projects that were undertaken to realize these objectives, were strongly influenced by discussions with PAB members, both formally at PAB meetings and informally with individual PAB members, especially the NFC. For example, the Manitoba Department of Natural Resources, which began its NFA ecological research and monitoring program in 1985, was intensively investigating six lakes in the LWCN project area:Cross, Sipiwesk, Stephens, Split, Rat, and Threepoint. To avoid duplication of effort, these lakes were not investigated under FEMP. In another instance, a proposed DFO intensive investigation of Playgreen Lake (similar to its previous case study of Southern Indian Lake) was not pursued at the request of the NFC; instead, one of the alternative projects that DFO initiated was a study of resource harvesting data to assess their suitability for use in a social impact assessment.

The other important determinant of FEMP was the principles of environmental impact assessments (EIAs). These principles include: 1) the determination of a program focus, a process commonly referred to as scoping; 2) the recognition of the important interrelationship between socioeconomic effects and environmental impacts; 3) the need for a sound scientific foundation for EIAs; and 4) the development of a program strategy and explicit objectives. FEMP embodied these EIA principles, even though it was not a true EIA. Traditionally, an EIA compares measured pre-project environmental conditions (or at least conditions that existed during the construction period) with anticipated post-project conditions. With the commencement of FEMP approximately ten years after construction of the major components of the LWCN project, post-project conditions were measured and, because of limited pre-project data, pre-project conditions were often estimated.

Determining observed post-project conditions as impacts of the LWCN project, one objective of Claim 18, requires two distinct but closely related components: 1) evidence of causality between observed ecological conditions and the project; and 2) an understanding of the social values of the people affected by the project. Establishing causality requires sound scientific research, based on an understanding of species ecology and a knowledge of the physical, chemical, and biological changes that have occurred since the project. A sound scientific foundation is particularly important in investigating the effects on higher trophic levels, like fish, in a complex and severely altered environment, such as the aquatic environment in the LWCN project area.

Characterizing an ecological change as a significant impact of the project depends upon the magnitude of the change, its severity, and its spatial and temporal characteristics. Further, characterization of a project impact as adverse, beneficial or neutral introduces a valuation, usually an economic valuation, which is primarily anthropocentric and ethnocentric. In other words, the valuation depends on the value of the affected resource to people in a particular social context and not to the ecosystem as a whole. The social context in which this valuation occurs in Canada is that of the dominant social group, a European-descendent, urban population living in southern Canada. This valuation differs markedly from that of native groups, for whom water issues transcend strictly economic, environmental or recreational concerns; they are a matter of identity.

Unfortunately there was insufficient socioeconomic information available on the six native communities to adequately assess the full implications of ecological changes to them. For example, lack of information on domestic fish consumption patterns in the communities prevented a full understanding of the socioeconomic effect of elevated mercury levels in fish following flooding. PAB members recognized the inadequacies of the existing socioeconomic information and individually and collectively tried to address this need. For example, DOE and DFO had numerous discussions on this subject with the NFC and also solicited direct community input into some FEMP projects. These initiatives met with only limited success. Consequently, FEMP was conducted, primarily, as a scientific investigation. It was expected that FEMP results, along with the results of Manitoba's and Manitoba Hydro's NFA studies and input from the native communities, on their socioeconomic values, would ultimately allow an evaluation of impacts of the LWCN project on the native communities.

FEMP OBJECTIVES

Four objectives were formulated for FEMP: 1) to the extent possible, determine pre-project conditions in the FEMP study area; 2) measure post-project conditions in the FEMP study area; 3) increase our understanding of the significant factors that could affect future ecological conditions in the FEMP study area; and 4) advise the public of FEMP results, ensuring that this information is presented in formats appropriate to the intended audiences.

Realization of the first three objectives required: 1) compilation and evaluation of relevant historical data, as well as the collection of data on post-project conditions, to establish temporal trends; 2) compilation and evaluation of spatial data to determine the extensiveness of any temporal changes; 3) quantitative data to determine the magnitude of change; and 4) scientific research, as well as monitoring activities, to develop an understanding of why the changes occurred. An understanding of why the changes occurred was necessary: 1) to determine the cause of the change, particularly to distinguish between anthropogenic and non-anthropogenic causes (e.g. natural variability); 2) to project expected future conditions (e.g. the estimated time for mercury levels in fish to return to pre-project levels); and 3) to assess the viability of potential remedial and mitigatory measures.

There were three principal factors that influenced the selection of subject matter for investigation under FEMP: 1) the perceived environmental concerns of the native communities; 2) the departmental mandates and expertise of DOE and DFO; and 3) the pre-FEMP knowledge about environmental conditions in the FEMP study area and the state-of-the-art of the relevant environmental disciplines. For example, mercury levels in the environment are a vitally important concern of the native communities. A previous study in the FEMP study area conducted in the early to mid-1980s, had established that mercury levels in fish in the Churchill River Diversion area were elevated following the LWCN project; however, methodology available at the time was not sensitive enough to directly measure the very low concentrations of mercury in water. Recent improvements in methodology have enabled the direct measurement of total mercury in water and of the even smaller concentrations of methyl mercury in water, the form of mercury that accumulates in fish. Consequently, measurements of total mercury and methyl mercury in water were conducted under FEMP, thereby addressing community concerns about mercury in their drinking water and increasing our understanding of mercury dynamics in the aquatic environment, such as mercury speciation and spatial distribution.

The subjects that were selected for study under FEMP were: water quantity and quality, sediment and morphology, mercury, fish and aquatic life, waterfowl, and resource harvesting. The geographical focus for these FEMP projects was the immediate vicinity of the six native communities.

A wide variety of scientific methodologies were employed in the pursuit of the FEMP objectives. Examples of some of these methodologies include: 1) calculation of pre- to post-project changes in lake surface areas from images transmitted by Landsat satellites; 2) measurement of stream flow at the outlet of SIL into the CRD using ultrasonic principles; 3) establishment of a community-run program to assess the bacteriological quality of the community's drinking and recreational waters; 4) analysis of sediment cores from the lake bottom of SIL for radioactive lead and radioactive cesium to determine rates of sediment deposition; 5) interpretation of a series of air photos to classify shoreline characteristics and to estimate sediment production at sites undergoing active erosion; 6) investigation of the groups of bacteria responsible for mercury methylation and demethylation and of the factors affecting these processes; 7) analysis of an extensive data base to assess the biological and economic health of the whitefish fishery at SIL e.g. whitefish numbers, grade, and condition; catch per unit effort; estimated net income for SIL fishermen; etc.; 8) surveys of benthic populations, an important food source for bottom-feeding fish, to determine spatial and temporal trends; 9) aerial surveys and hunter interviews to estimate waterfowl numbers; and 10) review of resource harvesting data and an examination of the additional lines of quantitative inquiry required for a social impact assessment of the LWCN project on the native communities.

Realization of the fourth FEMP objective, advising the public of FEMP results, required the determination of appropriate communication products based on the complexity and the importance of the material to be communicated and on the needs of the intended audiences. On this basis, three communication products were produced. The first product was the FEMP Report Series, in which a series of over twenty reports presented the interim findings of FEMP; the intended audience for this series was PAB. The second communication product was a videotape, entitled "Changes" that was produced in Cree and English versions; the intended audience was the residents of the native communities. The third communication product was the FEMP Final Report, which provided complete documentation of FEMP's history, objectives, methods, and results; the intended audience was the general public.

Addressing the information needs of the native communities was particularly challenging for the following reasons: 1) they had the greatest need to know because of their strong traditional ties to the resources of the LWCN project area; 2) the nature of their informational needs differed from the other FEMP audiences (e.g. the need to know whether mercury in fish, an important dietary staple in these communities, could be seen, smelt or tasted); and 3) the cultural distinctiveness of these communities. A videotape format was selected because the oral form of Cree is more widely understood than the written form and because videotaped interviews would enable the communities' residents to express their specific environmental concerns in their own words. The interviews, usually accompanied by visuals to illustrate the speaker's comments, were interwoven with graphics and brief narratives on the relevant FEMP results to produce the FEMP videotape.

CONCLUSIONS

A summary of the major FEMP conclusions is presented in this section, according to the six FEMP subject themes identified previously in this report. A seventh theme, future studies, draws some observations from the FEMP experience for consideration in the planning and implementation of future multi-disciplinary environmental studies, especially in the LWCN project area. Recommendations based on these conclusions are presented in the next section.

Water Quantity and Quality

Comparison of the regulated and estimated natural conditions for the period 1979 to 1988 showed the following changes in annual mean discharge: 1) the mean flow of the Churchill River at Missi Falls decreased from a range of 600 to 1700 $m^3 s^{-1}$ under estimated natural conditions to, usually, 13 to 200 $m^3 s^{-1}$ under regulation, (except for brief excursions to flows as high as 1400 $m^3 s^{-1}$); 2) the mean flow of the Burntwood River at Thompson increased from an average of 93 $m^3 s^{-1}$ under estimated natural conditions to an average of 888 $m^3 s^{-1}$ under regulation; and 3) the mean flow of the Nelson River at Kettle Dam increased from 2170 $m^3 s^{-1}$ under estimated natural conditions to 2980 $m^3 s^{-1}$ under regulation. There were also significant differences in the seasonal pattern of stream flows. For example, while the estimated natural annual mean flow, for 1979 to 1988, was not significantly different for the Nelson River as it enters Cross Lake compared to regulated flows (1829 $m^3 s^{-1}$), the mean June to August discharge for the period 1979 to 1988 was 670 to 770 $m^3 s^{-1}$ lower than estimated natural flows and the mean December to February discharge for the same period was 520 to 750 $m^3 s^{-1}$ higher than estimated natural flows. The reversal of the seasonal pattern on the lower Nelson River is obscured by the addition of the diverted Churchill River flows which have caused even regulated low summer flows to be as high or higher than what they would have been otherwise. Overall, the alteration in seasonal distribution of flows has shifted 7% of the combined annual delivery of the Churchill and Nelson rivers to Hudson Bay from the open-water season to the ice-covered months of November to May.

Perhaps the most dramatic effect of regulation on the lower Nelson River flows is that seen in the day-to-day regime. For example, at Kettle Dam, most of the day-to-night decreases in hourly mean discharge were over 2000 $m^3 \cdot s^{-1}$ in winter and were commonly almost 3000 $m^3 \cdot s^{-1}$ in summer. Large fluctuations during the ice-covered period can affect the strength and stability of the ice cover and change surface ice conditions, reducing the trafficability of the ice for both animals and people.

Changes in the hydrologic regime has also produced significant changes in the surface areas of lakes. Some examples are: 1) Southern Indian Lake increased from 2082 km^2 to 2377 km^2; 2) Notigi Reservoir (733 km^2) was created by the incorporation of a number of pre-project lakes (total surface area of 182 km^2) and by extensive terrestrial flooding (551 km^2); 3) Cross Lake was intermittently dewatered, causing 300 km^2 of lake bottom to be exposed each summer; and 4) three larger lakes along the lower Churchill River have been reduced in area by 39 to 76%.

The water quality in the FEMP study area, during the 1987 - 1989 FEMP water quality study period, generally met the Canadian Water Quality Guidelines for drinking water, recreational uses, and protection of aquatic life, although there were some exceptions. These exceptions were: 1) mean turbidity levels exceeded the drinking water guidelines at all sites; 2) mean extractable aluminum (Al) and total copper (Cu) exceeded the aquatic life guidelines at all sites; 3) mean extractable iron (Fe) exceeded the drinking water and aquatic life guidelines at all three natural sites, at sites along the CRD, and at the outlet of Split Lake; 4) total lead (Pb) occasionally exceeded the aquatic life guideline at the outlet of Split Lake; and 5) there were sporadic occasions when the aquatic life guidelines were exceeded for total lead (Pb), cadmium (Cd) and zinc (Zn) in the natural rivers and at sites on the CRD.

An assessment of changes in water quality from the pre-project period (1972 - 1973) to the post-project period (1987 - 1989) was not possible for all the FEMP water quality sites because of the lack of pre-project data. However, for those sites with sufficient data, the following general changes were noted: 1) the natural river sites showed little change; 2) the CRD sites had higher post-project turbidity levels, caused by bank and shoreline erosion; 3) the CRD sites experienced significant changes, such as decreases in hardness and alkalinity, that were a reflection of the differences in water quality between the diverted Churchill River water and the pre-existing Rat and Burntwood rivers; and 4) a number of variables declined at the outlet of Split Lake (e.g. hardness, conductivity) as a direct result of the diversion, but no increase in annual mean turbidity was observed. Changes in some variables, such as an increase in extractable Fe, were inferred for the Split Lake outlet on the basis of current differences in concentration between the Burntwood and Nelson rivers and the relative contribution of these rivers to total inflow at Split Lake.

The water quality - water discharge relationships derived from the FEMP data were generally too weak to offer much predictive ability, although there were several important exceptions, including the relationships for non-filterable residue (NFR) and turbidity in the Burntwood River at Thompson and for turbidity and alkalinity in the Burntwood River at the inlet to Split Lake. Many discharge-correlated variables experienced a shift from negative correlations prior to development to positive correlations during the FEMP study for some sites along the CRD and for the outlet of Split Lake; this shift was due to the increased importance of shoreline erosion.

Distinct seasonal trends that were evident included lower chlorophyll a concentrations at several sites and elevated nitrite-nitrate (NO_2-NO_3) concentrations under ice cover at most sites. These trends might have been the result of the imposition of light limitation on algal growth by accumulated snow and ice cover and a lower photosynthetic demand for nitrogen at the lower light levels and cooler temperatures under ice cover. Several apparent changes in seasonal patterns from the pre- to post-project periods were noted, but none could be conclusively attributed to the LWCN project.

Sediment and Morphology

On the basis of the results of a FEMP pilot project conducted along selected areas of the CRD, it was concluded that air photo interpretation is a feasible method to classify shoreline characteristics and to estimate sediment production at sites undergoing active erosion. For example, comparison of 1972 and 1985 air photos for Footprint and Honeymoon lakes showed the following changes in classified shorelines: 1) an increase in shorelines with shallow water or floating vegetation from 14 to

83 km; 2) an increase in shorelines with standing debris from 0.2 to 56 km; 3) an increase in eroding shorelines from 4 to 40 km, indicating the potential for widespread sediment production; and 4) an increase in cleared shorelines from 4 to 71 km, the result of an attempt to reduce one negative impact of flooding. A comparative analysis of the 1972 and 1985 air photos, along with topographic data, was used to generate quantitative estimates of sediment production at an actively eroding site, a small island in Footprint Lake. It was found that the island's area decreased by approximately 6200 m^2 and that the shoreline perimeter decreased by approximately 170 m. Further, on the assumption that 50% of the shoreline recession was due to erosion, rather than inundation, and that the depth of eroded sediment was 2 m, it was estimated that the total volume of material removed from this site was in the order of 6000 m^3.

In general, erosion to date along the riverine reaches of the CRD has not been nearly as serious as was predicted in pre-project studies. For example, sediment delivery to Split Lake from the CRD is estimated at slightly less than one million tonnes per year; while this amount is approximately ten times pre-diversion levels, it is much less than the projected estimates of six million tonnes per year. It might be overly optimistic, however, to assume that erosion rates will necessarily diminish in the near future. As sites erode, an increasing length of bank tends to be exposed so that volumetric rates of erosion could increase with time, even if the rate of bank recession slows down. Also, if gradual river bed degradation is proceeding at some points, banks that appear stable may eventually be undermined and begin to crumble. On the other hand, initial erosion at some sites can slow or stop as bedrock is reached. It thus appears that projection of future erosion rates and quantities of sediment subsequently generated are subject to considerable uncertainty and could not be improved substantially without extensive field studies.

The most extensive data record on sediment production is at Thompson. Turbidity briefly returned to predevelopment levels, at Thompson following the LWCN construction period, but has since increased significantly. Of particular interest is the apparently increased incidence of higher turbidity levels at Thompson, i.e. turbidity levels in post-project years are higher for a greater proportion of the year than in pre-project years. Although it is not known how representative the Thompson site might be of the rest of the CRD with respect to this apparent change, its location downstream of some of the major erosion sites along the CRD may make it a good indicator site.

Mercury

A mercury duration model was developed based on rates of mercury methylation and demethylation observed in reservoirs of various ages, located primarily in northern Manitoba. This model indicated that there will be a slowly accelerating rate of decline in the net production of methyl mercury, the predominant form of mercury found in fish. Net methylation rates are expected to be reduced by 50% in an estimated sixty years; an additional twenty years would be required before pre-development values are reached.

It is important to note that it is not the age of the reservoir per se that is the critical factor in determining mercury levels in fish, but rather the relative availability of fresh organic matter (i.e. the amount and type of vegetation flushed into the water). The model's prediction of a decline in the balance between the rates of mercury methylation and demethylation over time was based on a decline over time of available organic matter; this point was clearly illustrated in the case of Sipiwesk Lake. The mercury methylation and demethylation rates observed in Sipiwesk Lake in 1987 were higher than would have been expected given the age of this reservoir (flooded in the early 1960s). Since the operation of Jenpeg Dam in 1976, Sipiwesk Lake levels have been low in summer and high in winter, the reverse of most hydroelectric reservoirs. Recolonization by fast growing vegetation of the draw down zone in summer and the subsequent flushing of this material into the lake during periods of high water is probably providing a continuous source of fresh organic matter, thus stimulating ongoing mercury methylation.

Recent improvements in methodology enabled the direct measurement of total mercury and methyl mercury levels in water. It was found that total mercury concentrations in water were not higher in the flooded reservoirs than in a non-flooded reference lake, Granville Lake; however, methyl mercury concentrations in water were generally higher in the reservoirs than in Granville Lake. Mean total mercury concentrations ranged from 1.07 $ng{\cdot}L^{-1}$ (Notigi

West, 1989) to 2.10 $ng \cdot L^{-1}$ (Thompson, 1989); mean methyl mercury concentrations ranged from 0.017 $ng \cdot L^{-1}$ (Methyl Bay in SIL, 1989) to 0.054 $ng \cdot L^{-1}$ (Stephens Lake, 1989). These values were substantially below the upper limit of the Canadian Drinking Water Guideline for total mercury levels in water of 1000 $ng \cdot L^{-1}$.

FEMP investigations found that the same major metabolic groups of bacteria were responsible for the majority (in some cases, all) of the mercury methylation and demethylation activity observed in the flooded and non-flooded sampling sites. This finding indicates that it may be difficult to develop mitigative measures based on the selective inhibition of the methylators or stimulation of the demethylators. As noted previously, the most important factor affecting these processes is the availability of organic matter; however, there is some evidence that oxygen availability and sediment deposition may also be relevant. Additional research is necessary to assess the viability of possible preventative or remedial measures based on controlling these factors. Currently, the only viable mercury mitigatory measure is fish management practices (e.g. recommending the consumption of fish with low mercury levels, such as whitefish).

Measurements of mercury levels in fish, in the mid- to late - 1980s, in eight lakes by FEMP and by the Manitoba Department of Natural Resources found the following: 1) mean standardized mercury levels in whitefish in all lakes sampled were below the Canadian guideline of 0.5 ppm; 2) mean standardized mercury levels were below 0.5 ppm for walleye and pike in Cross Lake and for pike in Split Lake; 3) mean standardized mercury levels in walleye in Split Lake hovered around the 0.5 ppm mark, ranging from 0.42 to 0.61 ppm; 4) mean standardized mercury levels in pike and walleye for Southern Indian, Issett, Sipiwesk, and Stephens lakes ranged from 0.5 to 1.0 ppm; and 5) mean standardized mercury levels in pike and walleye for Rat and Threepoint lakes ranged from 1.0 to 1.5 ppm.

Mercury levels in the residents of the six native communities continued to be tested by Health and Welfare Canada. During the late 1980s, all values were below 80 ppb, with the exception of one individual in South Indian Lake whose level was between 80 and 100 ppb. The majority of the values were less than 20 ppb, the level which is considered normal for adults. A few women of child bearing age in four of the six communities, most notably South Indian Lake, had values between 20 and 80 ppb. Values greater than 20 ppb for women of child bearing age are a concern because of the uncertainty of the risk of mercury exposure to the fetus.

Fisheries and Aquatic Life

The commercial fishery at SIL was the largest in northern Manitoba prior to impoundment; however, following impoundment this fishery collapsed. Measurements of biological indicators conducted under FEMP showed that the biological status of the whitefish fishery has not returned to pre-impoundment values. For example, grade, a major determinant of whitefish prices, is determined by the number of *Triaenophorus crassus* cysts per 45 kg. Prior to impoundment, cyst counts were less than 40 (export grade); in 1987, cyst counts were 51.9 for Region 4 of SIL and 74.1 for Region 5 of SIL (continental grade). (Regions 4 and 5 are the most important commercial fishing areas in the lake). Another example is the catch per unit effort (CPU) values. In 1987, CPU was 8.44 for Region 4 and 9.75 for Regions 4 and 5 combined; prior to impoundment, in 1972, CPU was 23.1.

The main factor affecting CPU is the abundance of fish and their movements. Observations by SIL fishermen that large numbers of fish were congregating below Missi Falls, unable to swim upstream past the dam and into SIL, were investigated under FEMP in 1986 and 1987. Large numbers of fish were caught below Missi Falls in both years; whitefish dominated the catch in nearly all samples. Estimated numbers of whitefish reached a high of 88,764 in September 1986. In 1986, a year when the mean discharge from June to August approximated that of pre-impoundment conditions, the number of whitefish was highest in the autumn. Most of these fish, which were in good condition, appeared to have originated from SIL. It was concluded that these fish were trying to return to SIL to spawn. In 1987, a year of lower flows and higher water temperatures than 1986, the number of whitefish was highest in the summer. Most of these fish appeared to have originated from the lower Churchill River lakes downstream of Missi Falls and were in poorer condition than the 1986 fish. It was concluded that they were trying to escape the warmer waters of the downstream lakes.

In addition to the investigation of whitefish populations in SIL, a study of pike population dynamics, that was begun in 1976, was extended to 1988 under FEMP. A downward trend in CPU and in condition factor indicate that the adult pike population in Wupaw Bay, the SIL area sampled in this study, has suffered since impoundment. The decline in pike was attributed to post-impoundment changes, such as increased water depth, which rendered Wupaw Bay habitats less suitable for pike.

A study of the economic performance of the commercial fishery at SIL was conducted in 1988. Results showed that the fishery was financially viable; however, it is important to note that 36% of the total revenue to the fishery that year came from a compensation fund and a provincial freight subsidy program. Three approaches were used to evaluate the economic performance of the SIL fishery in 1988: 1) determination of average net incomes, using the same methods as those in a 1980 study; 2) an alternative analysis that more closely reflected the fishermen's view (e.g. loan payments instead of depreciation); and 3) an estimation of the total community income from the fishery. Income from the compensation fund and freight subsidy program was included in all three calculations. The first method estimated the average income per fishing firm in 1988 at $8289; this represented an increase of 32% in real income from 1980. Using the second method, the 1988 average net income per fishing firm was an estimated $9,751. The third method included the wage labour paid out by the firms and an estimated economic valuation of the income-in-kind derived from the fishery (e.g. domestic fish consumption, opportunistic moose kills, etc.); the total community income from the fishery was estimated at $398,326 to $518,326.

A survey of benthic invertebrates, an important food source for bottom feeding fish, in the lakes in the vicinity of SIL, that had been conducted at regular intervals since 1973, was continued under FEMP. The lakes were classified into four groups, based on the changes in their water flow regime: three lakes on the lower Churchill River; five lakes flooded by Notigi Reservoir; two lakes below the Notigi Control Structure; and two lakes unaffected by the LWCN project. Standing stock for the lower Churchill River lakes is about 50% of pre-project levels, on a per-area basis; loss of almost half of the most productive lake areas has meant that the present total population of benthic invertebrates is only about 25% of that before diversion. Standing stock in the Notigi Reservoir has stabilized at about twice the pre-diversion levels, which combined with an areal increase of approximately four times, means that the present water body has approximately eight times more benthic invertebrate standing stock than previously. The two sampled lakes below Notigi, Wapisu and Wuskwatim lakes, experienced a similar sequence of events in which an initial high, post-project productivity, based largely on benthic organisms feeding on drowned vegetation, was followed by a trophic depression when organic matter was exhausted or rendered unavailable by siltation. The two reference lakes were East Mynarski and Wood lakes. Total standing stock numbers in East Mynarski Lake fluctuated considerably without apparent pattern over the course of the study. Total invertebrate standing stocks in Wood Lake were usually about one-half of the riverine lakes, indicating the extent of the influence of river-borne nutrients and their effects on benthic populations.

Surveys of benthic standing stocks were also conducted in 1987 and 1989 in Playgreen and Kiskittogisu lakes. The portion of Playgreen Lake located south of 8-Mile Channel had significantly more invertebrates than the northern basin in both 1987 and 1989; productivity was highest in the western section of the south basin of Playgreen that is located in the sediment plume from 2-Mile Channel. In Kiskittogisu Lake, standing stocks were significantly higher in the southern portion, the part of the lake that receives direct inflow from 8-Mile Channel, than in the more remote northern portion of the lake. The spatial differences in both lakes were likely the result of the diversion of nutrient and food-laden water by the channels. Standing stocks in both lakes were higher in the FEMP study than in 1971, probably because of methodological differences. Standing stocks were reduced in 1989 in comparison to 1987 and there was a difference in the abundance ranking; both changes were likely the result of drought conditions experienced in 1989.

A FEMP investigation was initiated of the genetic structure of whitefish populations in Playgreen Lake and the northern end of Lake Winnipeg, in response to claims by Playgreen Lake fishermen that the spatial distributions and seasonal movements of separate stocks have changed since the regulation of Lake Winnipeg. The results of the analysis indicated that there were at least two different stocks of whitefish, one stock uses sites in the north basin of Lake Winnipeg for spawning and the other utilizes Little Playgreen Lake for spawning. The same genetic similarities and differences were found before Lake Winnipeg regulation. However, it is premature to state that the population structure of the whitefish has not changed since regulation. An analysis of morphological data that is yet to be completed may allow for the identification of additional stocks not ascertained by genetic analysis.

Waterfowl

Aerial surveys of ducks and geese were conducted in the Norway House area in September 1986 and October 1987 and in the Nelson House area in September 1988. Considerable variation in numbers was observed depending on species, lake, and date of survey; but, as a rule, numbers were generally low. Comparison of the results of the surveys conducted in the 1980s with pre-project surveys conducted in the early 1970s, showed substantial reductions in numbers of ducks (e.g. dabbling ducks declined in the Nelson House area by approximately 97% and diving ducks by approximately 96% in the Norway House area). Small numbers of geese were observed in both survey periods; indeed, geese were not observed on several surveys.

It is risky to draw broad conclusions about waterfowl numbers on the basis of these two sets of surveys, however, because the surveys provide only a limited number of "point-in-time" counts. Furthermore, large between-year changes are not uncommon in waterfowl counts derived from aerial surveys.

The only other available data for these areas are annual breeding-pair surveys conducted in northern Manitoba by the United States Fish and Wildlife Service (USF&WS). Analysis of this data for the periods 1964 - 1975 and 1977 - 1988 showed that in the latter period there was a marginally higher (0.2%) number of dabbling ducks and a small increase (approximately 2.6%) in diving ducks. However, large year-to-year fluctuations occurred in both periods; thus, the means on which these changes were based would vary somewhat as individual year counts were added or subtracted. The apparent reductions in the dabbling duck use of the Nelson House area and of the diving duck use in the Norway House area do not appear to be reflections of long-term decline in regional populations, as represented by the USF&WS data, since no such trends were evident in this data.

It is postulated that habitat modifications resulting from the CRD may have rendered the Rat-Burntwood rivers area less attractive for dabbling ducks and to a lesser extent for diving ducks. Higher duck densities observed in the September 26, 1988 survey of Notakikwaywin Lake, a lake near Nelson House unaffected by the CRD, than in the affected lakes surveyed supports this hypothesis. Similarly, it is postulated that changes in the quality of the Playgreen Lake habitat may have been sufficient to reduce the attractiveness of Playgreen Lake to diving ducks in the fall.

Resource Harvesting

A FEMP investigation of the existing data on resource use by the NFC communities (primarily fishing data) indicated a number of socioeconomic effects, including: 1) substantial declines in per capita subsistence fisheries harvests at Cross Lake and Split Lake (for which some pre- and post-project data exist); 2) a sharp decline in commercial fish production at Cross Lake; 3) partial contamination of the fisheries by mercury at Nelson House; and 4) increased costs of production at Norway House and, possibly, Split Lake. Existing data, however, do not reveal the full suspected range of adverse effects.

For example, the fisheries data provide only limited information on harvesting effort and the trapping data provide none at all. There are no other continuous records that can be used as impact indicators for resource harvesting. Estimates of subsistence harvesting are discontinuous in time and space, and idiosyncratic in method. Also, there are insufficient data on other resource harvesting activities, such as hunting of waterfowl and large and small game, as well as the gathering of berries and medicinal plants, to permit any assessment of the LWCN project on them.

In addition to the limited existing data on resource harvesting, there is a problem of interpretation. For example, effort and return in fishing have responded to market forces, such as fish prices and alternative employment opportunities, and perhaps also to changes in the community and reserve economies, in addition to effects of the LWCN project. Furthermore, focusing exclusively on economic losses likely undervalues the importance of fishing to the affected communities. Therefore it is important that fishing and all resource harvesting activities not be assessed in isolation and out of context. Unfortunately, there has been no comprehensive social impact assessment (SIA), which would provide such a context, conducted in any of the five NFC communities or in South Indian Lake. (Although South Indian Lake was excluded from this FEMP study, partly because it was the subject of other socioeconomic studies, the conclusions from the FEMP resource harvesting study, in general, apply equally well to this community.) Until a SIA is conducted, it will be impossible to fully understand the implications of the bio-physical changes on the six native communities in the LWCN project area.

Future Studies

The FEMP experience clearly illustrated the necessity of adapting a holistic approach when investigating ecological changes in a complex and severely altered environment, such as the LWCN project area. In particular, a holistic approach requires: 1) the generation of a substantial temporal data base; 2) the incorporation of research as well as monitoring activities; 3) the recognition of the inter-relatedness of ecological changes in a dynamic and constantly evolving ecosystem; and 4) an understanding that the significance and implications of the observed changes depends upon the time horizon and point-of-view chosen.

Although some FEMP projects were new initiatives, many were a continuation of research and monitoring activities previously initiated in the FEMP study area. It was apparent from the results of those FEMP projects with long-term data bases that short-term conditions were not necessarily indicative of long-term conditions. For example, earlier results of the pike population in Wupaw bay, SIL indicated that the only major effect had been to produce a strong year class in 1977; however, continuation of this study under FEMP showed that the adult population has been negatively affected, as shown by a downward trend in catch per unit effort and in condition factor. Furthermore, data bases that are long-term and fairly extensive, such as the water quality data at Thompson, can be segmented into discrete periods that can be used to develop an understanding of impacts which are specific to a particular period of time. For example, a doubling in total phosphorus concentration between the pre- and immediate post-development periods was observed at Thompson.

Long-term data bases are invaluable in documenting that environmental changes have occurred, but it is research that provides the explanation of why the changes occurred. For example, mercury research in the CRD area began with the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA) and continued under FEMP. This research established that the reason for the elevated mercury levels in fish observed along the CRD was the increase in the net production of methyl mercury that was triggered by the extensive flooding of terrestrial organic material. Further research led to the development of a mercury duration model that suggests mercury levels will remain elevated above pre-project levels for approximately 80 years. Understanding why the changes have occurred can be used not only to make predictions, but also to provide a scientific basis for evaluating potential remedial and preventative measures.

To a considerable degree, an attempt was made to incorporate the results of concurrent, non-FEMP environmental programs in the FEMP study area into the analysis of the FEMP data and report preparation; integration of all results, however, must await full completion of all individual project reports, both federally and provincially. Even with this integration, a number of important environmental changes since the LWCN project affecting either the FEMP study area or beyond it, will not have been addressed. The downstream impact on Hudson Bay of the LWCN project is one outstanding example. The cumulative impacts of all changes in the FEMP study area since the LWCN project (e.g. the extensive 1989 forest fires) is another example. Addressing this full range of environmental impacts requires the recognition of the inter-relatedness of ecological changes over the entire ecosystem.

FEMP results have been presented in an accurate, clear, and objective manner, with only limited interpretation of their significance and implications. This format was necessary because interpretation of these results depends upon the reader's perspective, in particular the point-of-view and time horizon chosen. For example, erosion to-date along the riverine sections of the CRD has not been nearly as serious as was predicted in prediversion studies; nor does it appear that the erosion has been serious enough to substantially affect flows and water levels. Yet, as shown by a FEMP pilot project, measurable differences in shorelines have occurred causing varying degrees of shoreline erosion and sediment generation. This erosion, along with inundation, has resulted in debris-clogged shorelines, which have impeded access to and from the shorelines and travel along the waterways. Thus it would depend on the point-of-view chosen (e.g. viewing the river as a source of hydro generation or as a transportation corridor) whether the changes in the shorelines are perceived to be significant. An example of the importance of the selected time horizon in assessing the implications of the FEMP results is the mercury issue. The estimated 80 year period before mercury levels will return to pre-project values means that mercury will be an issue for the next few generations.

RECOMMENDATIONS

Water Quantity and Quality

It is recommended that the documentation of the FEMP hydrologic investigations be widely circulated to ensure that the basis for the derivation of the hydrologic information is well understood. An understanding of the changes to the hydrologic regime is essential in developing an understanding of the ecological changes in the aquatic ecosystem. For example, estimated natural flows for the Nelson River during the FEMP study period were lower than the long-term mean. Consequently, it was difficult to determine if the apparent changes in water quality at the inlet to Split Lake and in the water quality - water discharge relationships at the inlet and outlet to Split Lake were due to the LWCN project or to low flow conditions.

In general, additional data collection in the future will not enable any further understanding of those water quality changes that have already occurred in the FEMP study area. There are, however, three potential areas of investigation that may provide additional insight on some localized changes in water quality. First, an investigation should be conducted to determine if pre-project water quality conditions at two FEMP sites in the Outlet Lakes area could be inferred from existing pre-project data at nearby upstream sites; determination of pre- to post-project changes in water quality at these FEMP sites was not possible due to lack of sufficient pre-development data. Second, monitoring should be conducted at the Nelson River inlet to Split Lake and at the Split Lake outlet over a wider range of flows than that of the FEMP study period to discriminate natural from project-induced water quality changes, if any have occurred. Third, an evaluation should be undertaken of the inferred sediment deposition in Split Lake near the mouth of the Burntwood River on local water quality, e.g. deposition and future potential mobilization of associated heavy metals.

It is recommended that the FEMP water quality data base be augmented by the continued monitoring of water quality at Thompson, to assess long-term changes on the Churchill River Diversion, and the collection of water quality data at additional locations where future hydro dams will be built, to examine specific or localized impacts. Monitoring at Thompson should consist of two-year studies, repeated at five-year intervals, which repeat the FEMP study sampling and analytical methods exactly. Monitoring at future dam sites should consist of data collection for three years prior to construction, with a sampling frequency comparable to the FEMP study, to establish pre-development baseline conditions. Any future field activities should include an examination of the predictive ability of the water quality - water discharge relationships identified in the FEMP water quality study.

Sediment and Morphology

It is recommended that a classification system be developed to characterize shoreline types in the FEMP study area. Examples of such characteristics include: 1) standing inundated debris or vegetation; 2) actively eroding areas of shorelines; 3) bed rock controlled shorelines; and 4) treed muskeg shorelines with permafrost. Representatives from all four parties to the NFA should participate in the development of the classification criteria and in the priorization of shorelines for classification. The high cost of even a limited morphological field program in the FEMP study area necessitates the priorization of sites. Factors to consider in the priorization process include: 1) technical criteria (e.g. availability of large scale air photos); 2) physical characteristics of the site; and, most importantly, 3) the representativeness of the chosen sites as indicators of the changes of greatest interest to the area's users.

Field investigations are necessary to provide clarifying additional information in those instances where a definitive classification of shoreline types is not possible from an air photo interpretation. The determination of the rates of shoreline recession also require field investigations. For example, on-site verification of bank heights and of the ice content of eroded material would enable more accurate calculation of the volume of material eroded.

It is also recommended that a field investigation be conducted to document major sediment sinks along the Churchill River Diversion. This program would complement the identification of sediment sources that will be one result of the shoreline classification and monitoring program. Suggested study locations include Footprint, Threepoint and Rat lakes and especially Split Lake. Evidence suggests that delta formation is occurring at the inlet of the Burntwood River to Split Lake. Sediment deposition in Split Lake is of particular concern because the incoming sediment load is largest there, the lake is large enough to ensure sediment deposition, and there is an established fishery used by the residents of Split Lake and York Landing.

Mercury

It is recommended that investigations be continued for three mercury issues that were examined under FEMP. First, additional studies should be undertaken of the microbial mercury demethylation process, the more poorly understood of the two microbial processes regulating the net production of methyl mercury. Such investigations may result in the identification of possible measures for stimulating demethylation and thus potential mitigatory action.

Second, investigations should be conducted into the range and mechanism of the downstream transport of mercury in the FEMP study area. A recommended geographic focus for this study is Split Lake where mercury levels in pike and walleye appear to be uncharacteristically high for a non-flooded lake on the Nelson and Burntwood rivers. Third, regular periodic monitoring should be conducted of mercury levels in fish from lakes that are domestically important to the six native communities in the FEMP study area. Only commercially harvested fish are currently regularly monitored.

It is also recommended that future hydro projects in northern Manitoba, and especially along the CRD route (e.g. Wuskwatim Dam), should include mercury research and monitoring activities, as well as possible preventative measures, that apply and build on the results of the FEMP mercury program. These studies should include such activities as: 1) the measurement of methyl mercury in water in the reservoir and immediately upstream and downstream; 2) the monitoring of mercury levels in fish in the reservoir and immediately downstream; and 3) the measurement of methylation and demethylation rates in the reservoir, beginning before the reservoir is created.

The Wuskwatim Dam environmental studies should also include a pilot project of controlled burning of organic material to evaluate the effectiveness of this technique as a preventive measure and to assess potential adverse environmental side-effects. In addition, sediment deposition studies in the reservoir could be conducted to assess the role of sediment deposition in the net production of methyl mercury.

The newly constructed weir at the outlet of Cross Lake has caused concern among the residents of the Cross Lake community because of its potential impact on mercury levels in fish. Because no back flooding of bog or forest terrain is expected, the weir is not expected to cause increased mercury levels in fish. However, this assessment should be confirmed by a fish mercury monitoring program for at least two years after the weir is constructed.

Fisheries and Aquatic Life

A limited research and monitoring program to complete and/or follow-up on the results of fisheries and benthic studies in the FEMP study area is recommended. These activities should include periodic sampling of biological indicators of the Southern Indian Lake (SIL) fishery and completion of the whitefish studies in the Playgreen Lake area.

The results of the FEMP studies of the Southern Indian Lake whitefish fishery suggest that it may be showing marginal improvement or stabilizing at levels lower than pre-impoundment values. Periodic sampling should be conducted to collect data on key indicators such as catch per unit effort, grade, and condition in order to assess the long-term status of the SIL whitefish. Consideration should also be given to a concurrent program of data collection to continue the assessment of the long-term status of the pike population in Wupaw Bay, SIL.

Morphological analysis of whitefish in the Playgreen Lake/Lake Winnipeg area should be completed. This may allow for the identification of additional stocks not ascertained by genetic analysis. Additionally, a report should be prepared on a FEMP study undertaken, in 1989, to assess the use of 2-Mile Channel as a fish migration corridor between Playgreen Lake and Lake Winnipeg. Software problems have delayed the analysis of data from the dual-beam echosounder employed in this study.

It is also recommended that a pilot project be undertaken to evaluate various mechanisms to transfer whitefish over the Missi Falls Control Structure, in years of high discharge at Missi Falls. The results of a FEMP study suggested that when the mean discharge at Missi Falls from June to August approximated that of pre-impoundment conditions, the large numbers of whitefish observed below Missi Falls originated from SIL; when lower flows occurred, the whitefish below Missi Falls appeared to have originated from the lower Churchill River lakes. An evaluation of the mechanisms tested in the pilot project (e.g. a seining program) should include documented numbers of fish successfully transferred, an assessment of the critical factors affecting success, cost, and the impact on the SIL whitefish fishery. The pilot project should be implemented and evaluated with the support of the SIL fishermen, since their long-term involvement will be an important factor in selecting any mitigation measure based on the results of the pilot project.

There is some suggestion that whitefish may also be leaving SIL through South Bay and into the CRD. Consideration should also be given to a research program to investigate this possibility, with the assistance of the fishermen from South Indian Lake and possibly, Nelson House.

Waterfowl

It is recommended that future surveys of ducks and geese conducted in the FEMP study area be of sufficient intensity and duration to enable assessment of temporal and spatial trends, with some degree of confidence.

No additional amount of data collection now will enable any further assessment of changes which have already occurred in the numbers of ducks and geese in the FEMP study area since the LWCN project. The FEMP investigation utilized all existing historical and spatial data to assess waterfowl trends to-date. Additional data collection now, however, could provide a more comprehensive understanding of the current usage of the FEMP study area by waterfowl and provide baseline data for an assessment of future changes.

Potential specific locations for future surveys include the sites of proposed future dams and areas of particular importance to the domestic harvesting of waterfowl by the residents of the six native communities in the FEMP study area. Ground studies, as well as aerial surveys, should be considered.

The waterfowl surveys should be carried out with the cooperation of the native communities in the planning and implementation of these studies. Input from these communities is required to: 1) identify their waterfowl harvesting areas; 2) provide assistance in the field studies; 3) help identify critical sampling times; and 4) provide data on domestic waterfowl consumption.

Resource Harvesting

It is recommended that the appropriate parties to the NFA conduct a social impact assessment (SIA) of the LWCN project on the six native communities in the FEMP study area. An SIA involves the selection and justification of a basic paradigm of social change, the identification of appropriate variables and indicators, and a workable system for monitoring these indicators on a continuing basis.

Post-construction socioeconomic assessments in the LWCN project area have been oriented almost exclusively to the accounting and evaluation of damages for the purposes of compensation or mitigation, rather than to the understanding of the processes or the significance of social change as such. Damage accounting, however, has little analytic or predictive value, and it does not provide an adequate basis for systematic monitoring of project effects, without which predictions cannot be verified.

A SIA of the LWCN project effects on the six native communities in the FEMP study area requires a generic model of their economy that specifies its characteristics and properties. Data required to conduct a SIA include: 1) the level of harvesting effort; 2) the amount of domestic consumption; and 3) a better understanding of the social and economic organization of resource harvesting activities (e.g. native land tenure). Meeting this entire range of data needs would require a combination of survey, extended interview, participant observation, and archival research. Clearly, satisfying these data needs requires that the SIA must be community based, not only in implementation and execution but also in design and control.

Future Studies

It is recommended that FEMP results be incorporated into the design and implementation of the environmental impact assessments (EIA) of future LWCN project dams; in particular, the planned construction of a dam at Wuskwatim Lake on the Churchill River Diversion (CRD) offers the first opportunity to fully incorporate FEMP results into an EIA in this region.

FEMP results should be considered in the EIA for Conawapa, the next planned dam in the LWCN project. However, there are three considerations that will limit the full application of FEMP results in this EIA: 1) some environmental concerns investigated in the FEMP study area are not expected to be as great a concern for Conawapa because of its location and planned operation, e.g. mercury; 2) there are environmental concerns about Conawapa that were not issues in the FEMP study, e.g. brook trout; and 3) the EIA process for Conawapa is already proceeding. The EIA for the proposed Wuskwatim Dam, on the Churchill River Diversion, on the other hand, would provide an opportunity to implement many of the FEMP recommendations previously noted (and at an early stage) that would test FEMP predictions, expand the extent of and our confidence in the existing data bases, and address identified needs.

FEMP recommendations on sediment, morphology, and mercury, in particular, offer a wide scope of productive avenues to pursue in the Wuskwatim EIA. Potential sediment and morphology issues include: 1) testing of the erosion model developed by DFO for Southern Indian Lake; 2) development of a shoreline classification scheme; 3) continuation of the FEMP air photo interpretation to generate estimates of erosion; and 4) the initiation of field studies to ground truth information obtained from remote sensing techniques. Potential mercury issues include: 1) measurement of pre- and post-Wuskwatim Dam methylation and demethylation rates; 2) measurement of total and methyl mercury concentrations in water and fish; 3) investigation of the possible downstream transport of methyl mercury from Wuskwatim via fish and water; and 4) a pilot project to assess the effectiveness of controlled burning of organic material as a possible preventive measure in the accumulation of methyl mercury by fish. Other potential issues arising from FEMP that could be further investigated include: 1) waterfowl surveys; 2) benthic surveys, and 3) measurements of selected water quality variables, such as turbidity, before and after the construction and operation of Wuskwatim Dam.

It is also recommended that the necessity for a strong administrative framework be recognized early and incorporated into the design of all future major environmental research and monitoring programs. Like FEMP, all major environmental research and monitoring programs build on the results of past investigations and lay the foundation for similar investigations in the future; these programs do not, or rather should not, exist in isolation.

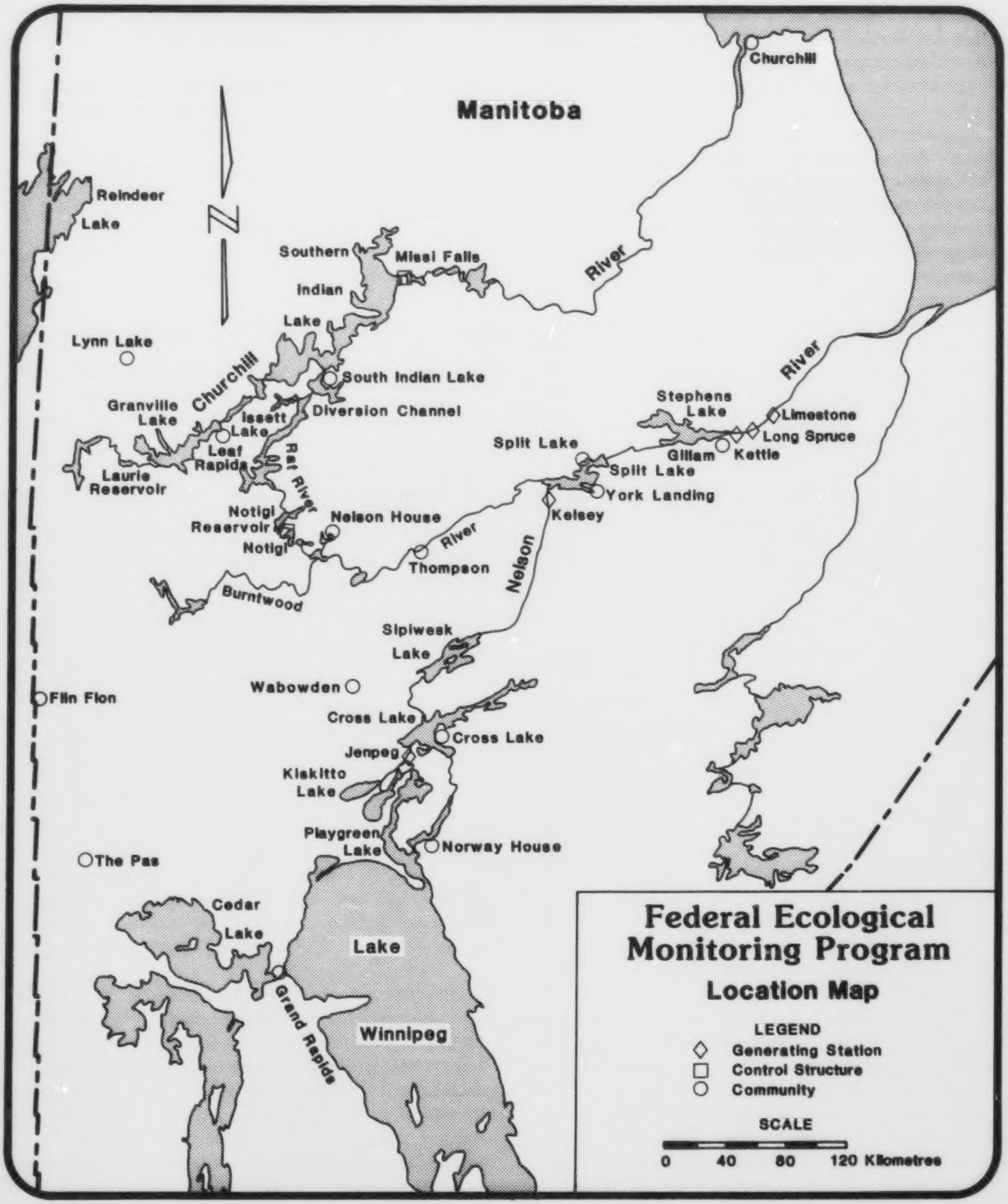
In order to ensure that a program achieves its full potential, a number of administrative tasks must be initiated early. These include: 1) the retrieval and standardization of existing data and the determination of methods used in past studies; 2) the need for program management and for scientific review of all program proposals and project findings; 3) the provision of secure and sufficient program funding, ensuring that enough flexibility is provided to enable reallocation of funds between years and projects as program requirements demand; 4) full documentation and permanent archiving of data; and 5) the planning and implementation of a vigorous and effective public information program.

Despite the importance of administrative tasks, they are frequently initiated only relatively late in a program; FEMP was typical in this regard. There are a number of reasons for the late establishment of administrative structures. First, the non-routine nature of these programs takes them outside the normal departmental operational experience. Second, the broad objectives and time frames of such programs places them beyond the mandate and resources of any one department. Third, there are constitutional uncertainties regarding responsibilities in water resource issues. The latter problem can result in a "tragedy of the commons" in that what is in the interest of all parties to have is no one's responsibility to provide.

Clearly, the strong administrative framework that is required to support the scientific and social investigation of complex environmental issues can best be provided through cooperative action of all involved parties. This would remove constitutional uncertainties and provide a large common pool of resources and experience. Cooperative action also offers the advantage that, through their participation, all involved parties will have a better appreciation of the program's conclusions and recommendations and will incorporate this knowledge into their decision-making process. The ultimate success of programs like FEMP will be their influence on the decision makers of today and tomorrow.

LIST OF ACRONYMS

CMMA	Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion
CPU	catch per unit effort
CRD	Churchill River Diversion
DFO	Department of Fisheries and Oceans
DOE	Department of the Environment
EIA	environmental impact assessment
FEMP	Federal Ecological Monitoring Program
LWCN	Lake Winnipeg, Churchill and Nelson Rivers
NFA	Northern Flood Agreement
PAB	Programs Advisory Board
p.p.b.	parts per billion
p.p.m.	parts per million
SIA	social impact assessment
SIL	Southern Indian Lake
USF&WS	United States Fish and Wildlife Service



Federal Ecological Monitoring Program

Location Map

Manitoba
Churchill
River
Reindeer Lake
Southern Indian Lake
Missi Falls
Lynn Lake
Churchill
South Indian Lake
Granville Lake
Diversion Channel
Issett Lake
Leaf Rapids
Rat River
Laurie Reservoir
Notigi Reservoir
Notigi
Nelson House
River
Thompson
Burntwood
Nelson
Kelsey
Split Lake
Split Lake
York Landing
Stephens Lake
Gillam
Kettle
Long Spruce
Limestone
River
Sipiwesk Lake
Wabowden
Flin Flon
Cross Lake
Cross Lake
Jenpeg
Kiskitto Lake
Playgreen Lake
Norway House
The Pas
Cedar Lake
Grand Rapids
Lake Winnipeg
LEGEND
◇ Generating Station
□ Control Structure
○ Community
SCALE
0
40
80
120 Kilometres

Volume

1

FEDERAL ECOLOGICAL MONITORING PROGRAM

Final Report

Volume 1

Environment Canada L'environnement Canada

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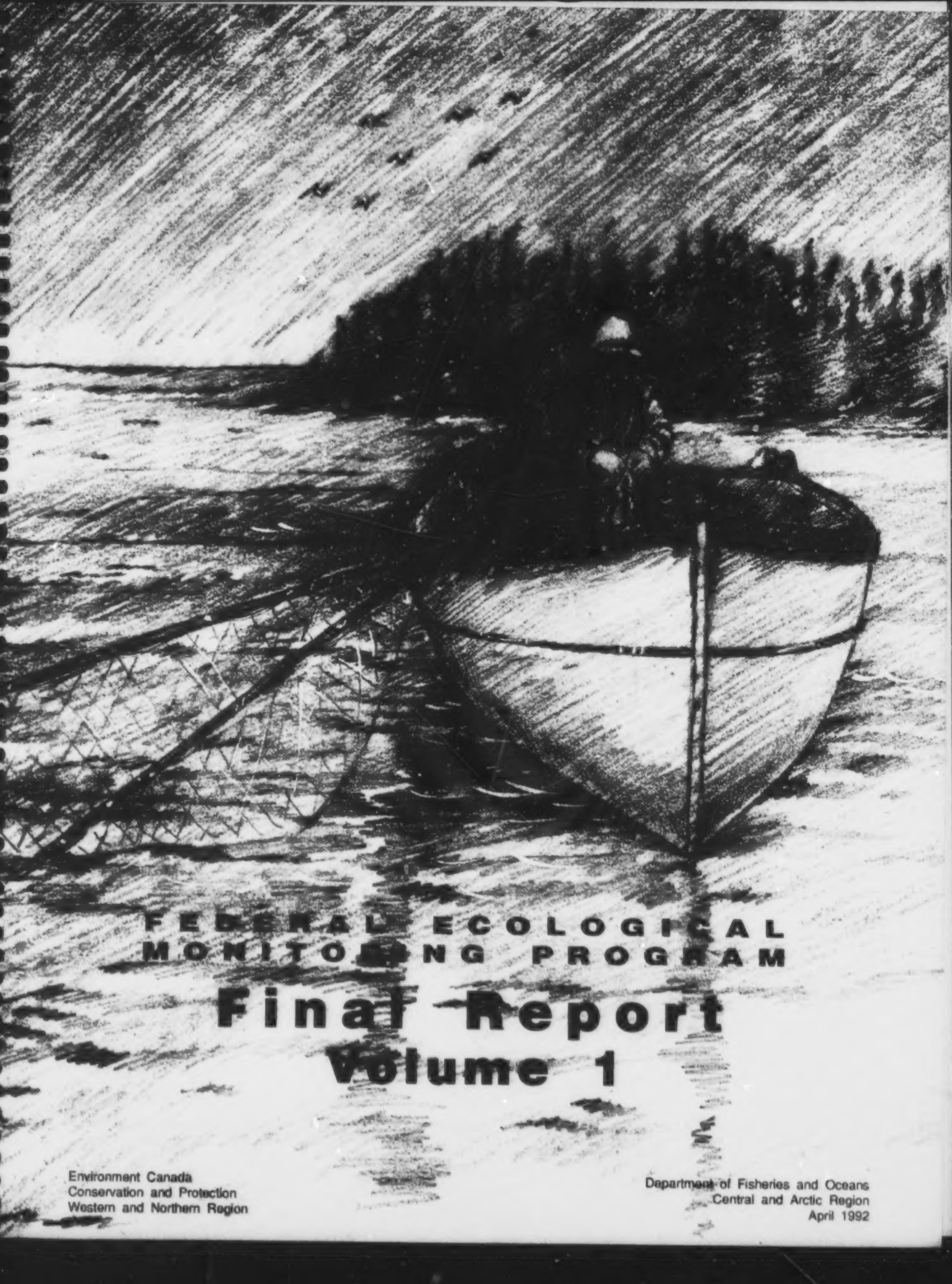

FEDERAL ECOLOGICAL MONITORING PROGRAM

Final Report

Volume 1

Environment Canada
Conservation and Protection
Western and Northern Region

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CHAPTER 1

THE FEMP STUDY AREA

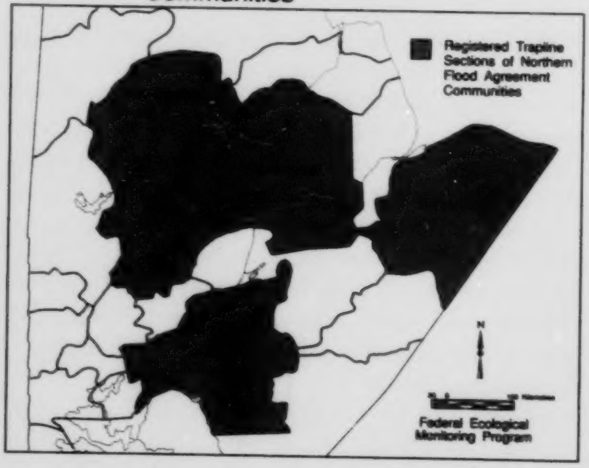
INTRODUCTION

In 1986, Environment Canada (DOE) and the Department of Fisheries and Oceans (DFO) began a joint, 5-year environmental research and monitoring program called the Federal Ecological Monitoring Program (FEMP). FEMP was an investigation of the environmental impacts of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project in northern Manitoba. Volume 1 of this report describes the background of FEMP: the study area (chapter 1); the area's water regime, (chapter 2); the program's strategy and objectives, (chapter 3); the program's scientific foundation, (chapter 4); and the program's reporting mechanisms, (chapter 5). Volume 2 of this report describes FEMP results: the socioeconomic importance of the environmental changes to the area's native communities, (chapter 1); a compilation of the program's results for Southern Indian Lake and the Churchill River Diversion area (chapter 2), the Outlet Lakes area, (chapter 3), and the Split Lake area, (chapter 4); and the program's conclusions and recommendations, (chapter 5).

LOCATION AND CLIMATE

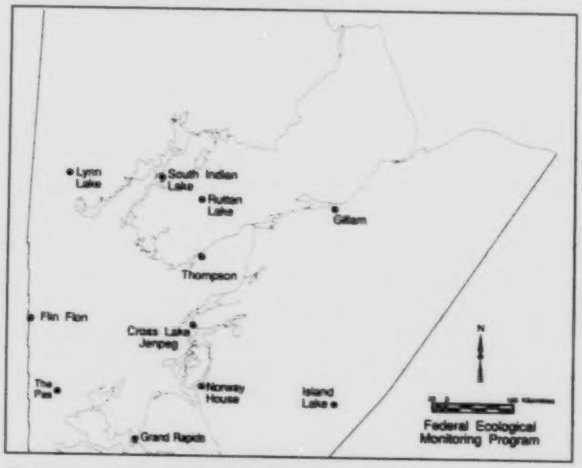
The LWCN Hydroelectric Project is a series of dams and control structures from Lake Winnipeg to Hudson Bay, on the Churchill, Nelson, Rat and Burntwood rivers. (See Map 1 at the back of this report.) The FEMP study area corresponded, approximately, to the resource areas of the 6 native communities affected by the LWCN Hydroelectric Project. (See Fig. 1.1.)

Figure 1.1 Resource Areas of the FEMP Native Communities


Registered Trapline Sections of Northern Flood Agreement Communities
N
Federal Ecological Monitoring Program

The FEMP study area in Manitoba's interior has a continental climate, consisting of long, cold winters and short, cool summers. The network of climate stations in northern Manitoba is limited; there are only 13 stations, at 11 locations, within and around the FEMP study area (Fig. 1.2). The ranges and extremes recorded for temperature, precipitation, snowfall, and growing degree days greater than 10°C for these 13 stations are shown in Fig. 1.3.

Figure 1.2 Location of Climate Stations in the FEMP Study Area


Lynn Lake
South Indian Lake
Ruttan Lake
Gillam
Thompson
Flin Flon
Cross Lake
Jenpeg
The Pas
Norway House
Island Lake
Grand Rapids
N
Federal Ecological Monitoring Program

Footnote: There are two stations, each, at Norway House and Grand Rapids

Figure 1.3 "Normals" and Extremes for Selected Climatic Variables in the FEMP Study Area, 1970 - 1989

Normal Values	**Extreme Values**	
Temperature		
0.2°C to -	3.3°	Grand Rapids Hydro,1987
5.2°C	-7.0°C	Gillam, 1972
Total Precipitation		
434.0 mm to	880.5 mm	Ruttan Lake, 1983
542.4 mm	319.0 mm	The Pas, 1982
Snowfall		
110.2 mm to	332.7 mm	Lynn Lake, 1988
239.3 mm	53.7 mm	Grand Rapids Hydro,1987
Degree Days >10°C		
758.8 dd to	964.9 dd	Grand Rapids Hydro, 1988
377.6 dd	216.6 dd	Gillam, 1978

Comparison of the meteorological data for 1970 - 1989, corresponding approximately to the construction and post-development period of the LWCN Hydroelectric Project, to the "normals" published by Environment Canada (for the period 1951 to 1980) showed, that while fluctuations away from normal did occur, no "abnormal" departures occurred for any significant periods of time. There was, however, a slight tendency for stations to display more years with above normal temperatures values and a tendency for stations to record more years with below normal snowfall amounts. Fig. 1.4 shows this data for 4 of the 13 stations.

Temperature trends recorded at the 13 stations showed a high correlation, as did the number of growing degree days greater than 10°C. There were also similarities in the recorded snowfall at the 13 stations, but not to the same extent as for temperature and growing degree days. There was no agreement in recorded total precipitation among the 13 stations. (Rainfall is caused mainly by convective activity that can occur on small scales, whereas snowfall is carried by large frontal systems that can affect a wide area.) Temperature and degree days recorded at these 13 stations were thus deemed representative of the FEMP study area while snowfall and total precipitation amounts and trends were confined to typifying smaller areas.

THE BOREAL FOREST

Description

The FEMP study area is part of the boreal forest or the taiga, an area that makes up 27% of the world's total forest or 17 x 10^6 km^2 in North America. The taiga meets the tundra in western Alaska, sweeps across the continent, swinging south of Hudson Bay and encompasses most of the island of Newfoundland, an area extending some 6 200 km from east to west and 500 to 800 km north to south.

The taiga is an area of circumpolar coniferous forest consisting of remarkably few species of plants. In the taiga, the dominant trees are conifers, particularly spruce, with other trees being pine, larch, birch, alder, and aspen. An important aspect of taiga vegetation is the presence of berry-bearing shrubs (e.g. blueberry, crowberry, etc.) that are important in the lives of taiga birds, mammals, and people. Another characteristic of the taiga is the usual presence of podzol soils. Podzol typically possess a surface humus layer of slowly decomposing coniferous litter; the humus is typically strongly acid.

The boreal forest affects the local climate. Within the forest, the ambient temperature is usually somewhat higher than outside the forest and the extremes are not as wide. Also, the needles and twigs catch the wind and slow it down so that windchill within the forest is less than outside it. Because of the remarkably little wind and the usually continuously sub-freezing winter temperatures, the snow cover of the taiga is typically soft and of low density, even though varying greatly in thickness from place-to-place and from year-to-year.

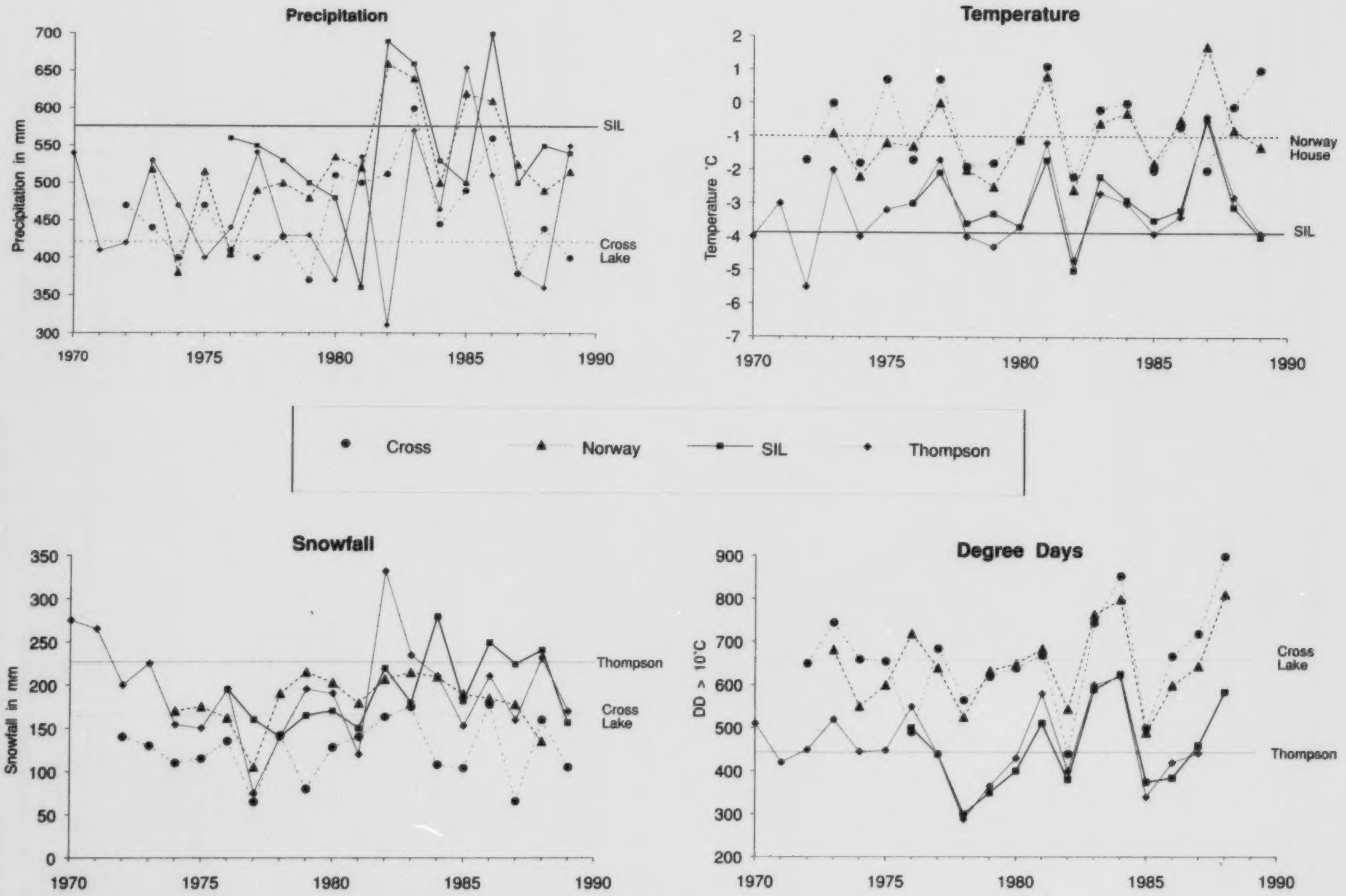
Predictions of future greenhouse-dominated climates postulate that the taiga will undergo more changes than any other forest type, possibly a large reduction in area from about 17 x 10^6 km^2 in North American to about 10.5 x 10^6 km^2, and a poleward shift in boundaries. (One estimate is that for every 1°C increase in global temperatures, there will be a northward shift in the forests of 100 km.) Such a poleward shift could result in a substantial loss of the taiga in the FEMP study area. Whether these predictions will be realized will depend on the interaction of many factors, not the least of which will be man's global response to the greenhouse effect.

Forest Fires

Because the taiga consists primarily of highly resinous coniferous trees, it is extremely susceptible to fire. Although wildfire was a regular occurrence in pre-contact times in North America, the frequency of wildfire has increased enormously since the arrival of Europeans.

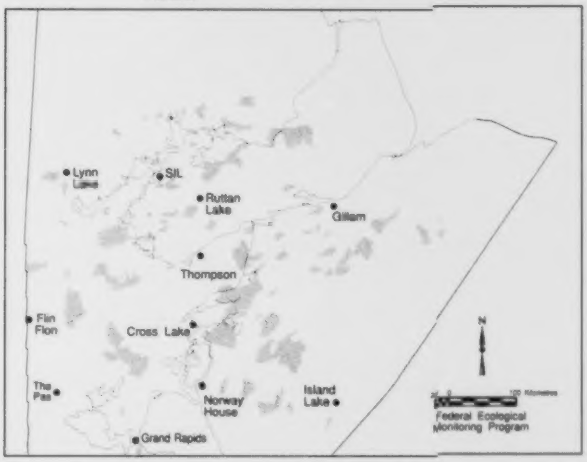
The summer of 1989 was a particularly bad year for forest fires in Manitoba, most especially in the boreal forests of northern Manitoba. Across Manitoba, 25000 hectares burned; $88.2 million was spent by the provincial government, mostly for fire suppression and evacuation. Unfortunately, there are no comparable figures available for the extent of the forest fire damage in the FEMP study area; however, as shown in Fig. 1.5, forest fires were extensive in the FEMP study area. These fires forced the evacuation of each of the 6 native communities in the FEMP study area and had a devastating impact on their resource areas.

Figure 1.4 Selected Examples of Departures from "Normals" for Selected Climatic Variables in the FEMP Study Area, 1970 - 1989



Footnote: Straight lines are the highest and lowest 30 year normals of the four selected stations.

Figure 1.5 Forest Fires in the FEMP Study Area, 1989

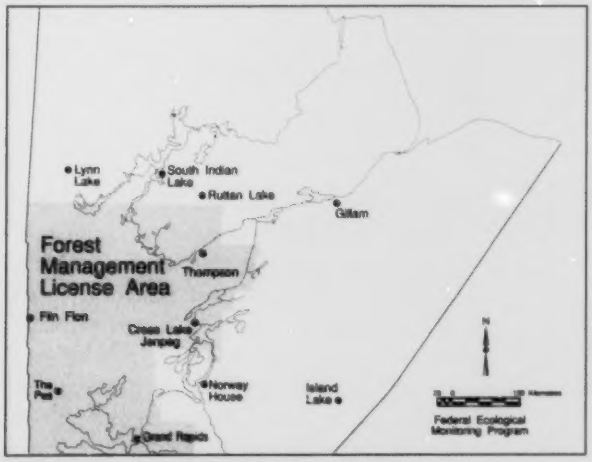

Lynn Lake
SIL
Ruttan Lake
Gillam
Thompson
Flin Flon
Cross Lake
The Pas
Norway House
Island Lake
Grand Rapids
N
Federal Ecological Monitoring Program

Forestry

In 1989, with the purchase of a crown owned pulp and paper mill at the Pas, Repap Enterprises Inc. was granted a forest management licence (F.M.L.) area of approximately 108 000 km^2 of Manitoba's boreal forest; this represents about 19% of Manitoba's land mass. Included in the F.M.L. area are the resource areas of 2 of the 6 native communities in the FEMP study area, Cross Lake and Nelson House (Fig. 1.6).

Repap has proposed to process the harvested timber by converting and expanding the existing manufacturing facilities at The Pas in two phases. In Phase I, the present unbleached kraft pulp and paper mill will be converted to a bleached kraft pulp mill and production increased from 400 to 500 tonnes per day. In Phase II, a new 1200 tonne per day bleached softwood (conifers), kraft pulp mill will be constructed and the 500 tonne per day pulp mill converted to produce 550 tonnes per day of hardwood (deciduous) kraft pulp. Should Repap proceed with their proposal, it will be subject to environmental impact assessments by the federal and provincial governments.

Figure 1.6 Repap's Forest Management License Area within the FEMP Study Area


Lynn Lake
South Indian Lake
Ruttan Lake
Gillam
Forest Management License Area
Thompson
Flin Flon
Cross Lake
Jenpeg
The Pas
Norway House
Island Lake
Grand Rapids
N
Federal Ecological Monitoring Program

Note: F.M.L. area extends below 53°N

MINING

The FEMP study area is located in the Precambrian Shield area of northern Manitoba, an area rich in metals: nickel, copper, cobalt, zinc, gold, silver, lead, and tellurium. The first major mining operation in northern Manitoba began in 1927 when Hudson Bay Mining and Smelting Co. Ltd. set up a pilot mill at what was to become the town of Flin Flon, near the Saskatchewan border. Since then, the mining industry has played an important role in the northern Manitoba economy and has been directly responsible for the creation of the towns of Lynn Lake, Snow Lake, Leaf Rapids, and Thompson. Thompson, located on the Burntwood River in the FEMP study area, has evolved from a mining town to the major service center of northern Manitoba, with a population of 15 000.

THE NATIVE COMMUNITIES

Introduction

There are 6 native communities located on the shorelines of the major rivers and lakes of the FEMP study area - South Indian Lake, Nelson House, Split Lake, York Landing, Cross Lake, and Norway House. (See Map 1.) Occupancy of the region by the predecessors of the residents of these communities dates back thousands of years.

The native people of this area have been in longer and more complex contact with European society than any aboriginal groups in Canada except for those of the Atlantic and St. Lawrence areas. Commercial exchange for fur dates from the 17th century and the area has served as a major transportation route into the interior of North America. Wage labour and the existence of a stratified occupational hierarchy have been facts of economic life in the region for at least two centuries. Since at least the 1880s, other economic developments, including commercial fishing, railway construction, mining, forestry, and white settlement, have added to the complexity of the social and economic life of the region.

Although neither wage employment nor the market system are foreign to these communities, there is typically a substantial level of economic activity that takes place outside of the market sphere. This resource-based subsistence activity does not constitute a separate and distinct economy, but rather is inextricably linked with wage labour and transfer payments.

Resource harvesting activity has traditional cultural and economic components which have continued within the mixed economics of these communities. The subsistence economy is as fundamental to the support of the communities' culture and social relations as it is to their economic structure. Extensive and intensive use of their resource areas, approximately represented by the registered trapline sections shown in Fig. 1.1, continues to take place and to contribute to the communities' cultural and economic well-being. In this sense, these "communities" extend well beyond that of their permanent settlements.

Though the framework of mixed subsistence based economies can be used in a general understanding of these northern native communities, it must be recognized that they are not identical. The degree of reliance upon subsistence and market components varies from community to community; the nature and extent of the impacts of the LWCN Hydroelectric Project on the resource base varies; and historically, the degree of isolation from industrial development has differed. Though all six communities are highly dependent on resource-based activity, there are differences among them in the importance of commercial fishing and trapping, in the presence of logging, in the degree of access to resources, and in the development of tourism facilities. Nonetheless, subsistence and access to the resource base remain significant to them all. A measure of the importance of the traditional, subsistence economy can be glimpsed from the multiple uses of fish shown in Fig. 1.7.

Figure 1.7 Traditional Uses of Fish

FOOD AND MEDICINE

Main Course:	A number of different methods of preparation are: fried, dressed; baked in oven, whole, dressed; baked in open fire placed on coals, whole; barbecued, on stick in front or above fire, whole or dressed; deep fried, dressed, cut up; smoked, dressed; and boiled, ground (bone and all) to make paddies.
Delicacies:	Pickerel cheeks; liver, fried from whitefish, maria, pickerel and sturgeon; fish eggs, (caviar) used as part of the mixture in bannock; sturgeon head, meat from the head gill area; sucker heads, fried or boiled.
Soup:	Juice from boiled fish made into soup by adding flour or oatmeal.
Infant and Child Feeding:	Juice from boiled fish used in bottles to feed infants; the tail of any fish considered the best for children because there are no bones.
Dogs:	Guts and bones, whatever was not edible for humans, was fed to the dogs.
Medicine:	Juice from boiled fish was kept in a jar by some and used as medicine for certain ailments.

OTHER

Child's Toys:	Air sac blown up and dried and used as a child's balloon; pebbles placed inside to make a rattle.
Glue:	The gill or throat area of a sturgeon was prepared (peeled/diced/boiled) and used as a very strong glue.
Fertilizer:	Guts often put into gardens to act as fertilizers.
Native Crafts:	Scales of certain fish were used to ornate native crafts.
Bait:	Leftover fish or guts used as bait by trappers.
Oil:	Sturgeon oil was used as lamp oil and a lubricant for tanning moose hide to make the hide softer.

Source: Adapted from letters of E. Scott, Cross Lake.

Community Profiles

Five of the six native communities - Cross Lake, Nelson House, Norway House, Split Lake, and York Landing - are located on reserve lands; local governments, organized under Indian and Northern Affairs Canada guidelines, are provided by elected chiefs and band councils. The sixth community, South Indian Lake, is located on provincial Crown land and is not a reserve; its government is organized under the guidelines of Manitoba's Northern Affairs Act. South Indian Lake is the only one of the 6 native communities that is not a signatory to the Northern Flood Agreement (NFA), an important 4-party agreement discussed in chapter 3.

The size of these communities is noteworthy in that they are among the largest native communities in Canada. The total population (status and non-status) of the six FEMP study communities is presently about 14000. By comparison, the entire population of the eight Cree bands in northern Quebec affected by the James Bay Hydroelectric Project is less than that of the 5 NFA communities.

South Indian Lake

The South Indian Lake community is situated along a narrows which joins South Bay to the main body of Southern Indian Lake. Part of the community's resource area has been flooded while other areas, downstream of Missi Falls, have been permanently dewatered. The majority of the population are status Indians, most of whom have affiliation with the Nelson House Band, dating back to the early permanent settlement of South Indian Lake somewhere near the turn of the century. However, there exists little interaction between the two communities, as a result of separate development. In 1988, the total population was 845 persons. Commercial fishing, trapping, and tourism comprise the principal local economic activities.

Nelson House

The core area of the community is located along the north shore of Footprint Lake. Part of the Nelson House resource area has been flooded by the diversion of the Churchill River along the Rat and Burntwood rivers. In 1988, 1,413 persons lived on reserve out of a total band membership of 2,569. Economic activity is based on trapping, hunting, fishing, and a local service sector.

Split Lake

The Split Lake Band has three reserves located around Split Lake, with the principal settlement on the northwest shore. The community resource area is affected by both the operation of the Churchill River Diversion and by the operation of hydroelectric installations on the Nelson River. In 1988, 1,163 persons lived on reserve out of a total band membership of 1,615. Trapping, hunting, fishing, and service industries are the principal economic opportunities.

York Landing

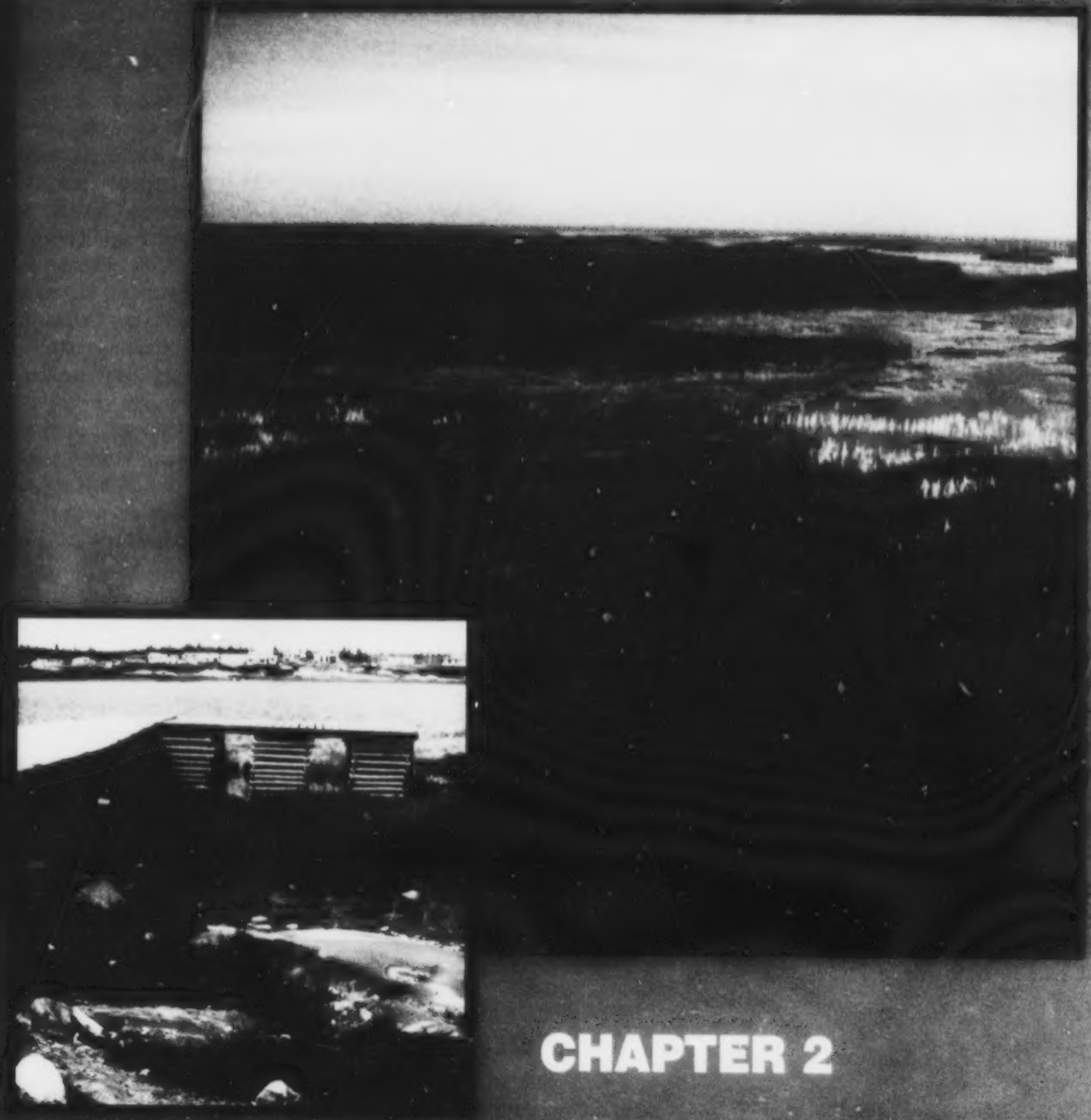
This community is located on the north bank of the Aiken River near the mouth where it empties into Split Lake. As a result of its relocation from York Factory near Hudson Bay in 1957, it has only a limited resource area, consisting of one community trapline in each of the Shamattawa and Split Lake registered trapline sections. In 1988, 9 band members lived on reserve and 326 on Crown land out of a total band membership of 538. Trapping is limited. Tourism provides additional economic activity in the operation of a goose camp near Hudson Bay.

Norway House

The Norway House reserve is located just downstream of the outlet of Lake Winnipeg. The community's resource area includes the Outlet Lakes which have been affected by Lake Winnipeg control works such as 2-Mile Channel. In 1988, a population of 2,648 lived on reserve out of a total band membership of 3,339. Commercial fishing, trapping, logging, construction, and service opportunities are the primary local economic activities.

Cross Lake

Five reserve parcels are located on the shores of the Nelson River where it enters Cross Lake. The location of the Jenpeg Dam 15 kilometers upstream from the reserve has resulted in the dewatering of Cross Lake in the summer months. In 1988, 2,337 persons lived on reserve out of a total band membership of 2,972. Trapping, commercial fishing, and log cutting are major economic opportunities.



CHAPTER 2

THE FEMP WATER REGIME

INTRODUCTION

"By the early 1600s, explorers searching for a North-West passage to India had mapped the estuaries of the Seal, Churchill, Nelson, and Hayes Rivers on Hudson Bay. In 1668, Radisson and Grossilliers traded furs at the mouth of the Nelson for great profit and within two years, the Hudson's Bay Company was formed with trading depots at the mouths of all the major rivers. At one depot, York Factory at the mouth of the Hayes River, the trade was particularly rich. It was discovered first by Henry Kelsey in 1690 and later confirmed by David Thompson in 1745, that the river leading to the depot was part of a larger system of channels that were connected to the interior of the continent. The valley of the Nelson and Churchill Rivers through the Canadian Shield was discovered and the passage from the docks of England though Hudson Bay to the western plains and mountains of the interior of North America was established" (Newbury, 1990, p. 3).

From the early days of the fur trade to the present-day hydroelectric projects, northern Manitoba's waterways have played a critical role in Manitoba's development. However, since long before the arrival of the Europeans, these rivers and lakes and their associated shorelines were, and continue to be, vital to the way of life of the local aboriginal people, providing them with transportation corridors, abundant natural resources, and a hospitable place to live.

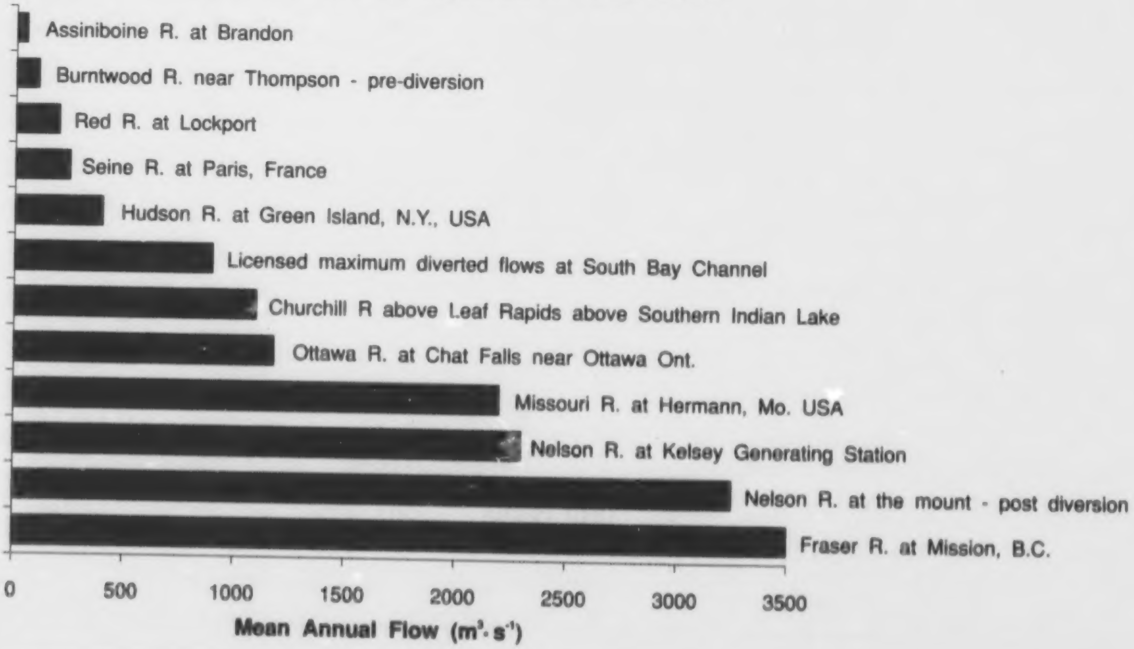
In this chapter, the natural regime of these waterways and the changes to it since the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project are discussed. A knowledge of the altered water regime is essential in understanding the FEMP results, and their implications.

THE NATURAL REGIME

The Nelson and Churchill rivers are two of the biggest rivers in western Canada, as measured by the size of their drainage areas and by their flows. Together these two rivers and their major tributaries - the Saskatchewan, Red, Winnipeg, Assiniboine, Qu'Appelle, English, and Rainy rivers - drain more than 1.2 million square kilometers (km^2) of the interior of North America. The mean annual discharges of the Nelson and Churchill rivers, along with those of other rivers selected for comparison, are shown in Fig. 2.1.

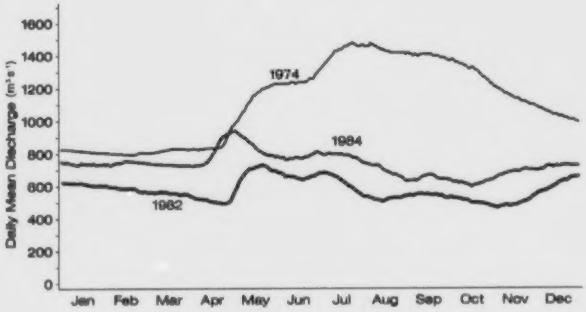
The flow of any river varies over the course of the year and between years. Factors which affect a river's natural flow include the river basin's climate, especially precipitation patterns and evaporation rates; the river basin's topography and soil permeability; the amount, type, and location of vegetation in the river basin; and the number and size of the lakes. In northern Manitoba where a

Figure 2.1 FEMP River Flows in Comparison to Other Rivers



significant amount of the year's precipitation is in the form of snow, natural river flows rise in the spring with the local runoff from snowmelt and spring rains. Fig. 2.2 shows how the Churchill River, which accumulates runoff from across the northern plains, may rise to a second peak in late June or July as the spring runoff finally arrives from the farthest western portion of the Churchill River drainage basin. Variation in flows between years is illustrated in Fig. 2.3.

Figure 2.2 Hydrograph of Churchill River at Granville Falls



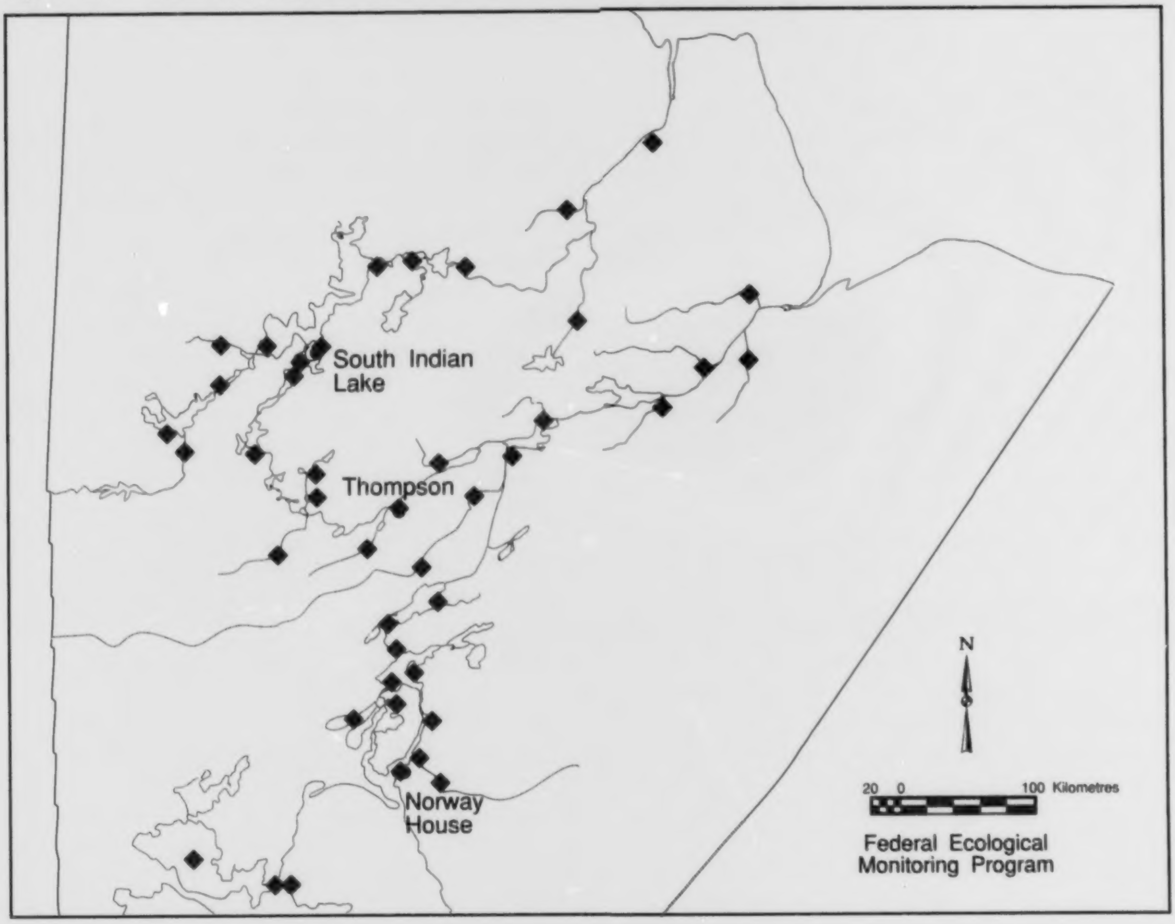
Point specific measurements of river flows and lake levels are made at a number of locations within the FEMP study area (Fig. 2.4). The hydrologic data generated from this network of sampling sites was used to calculate a water budget for the FEMP study area. One of the uses of the water budget was the determination of the changes in the water regime reported on in this chapter.

Figure 2.3 Selected Flow and Lake Level Extremes for the FEMP Study Area

Station Flows ($m^3 s^{-1}$)	**Period**[1]	**Mean**	**Min.**	**Max.**
Churchill River	1951 - 1973	808.73	479.00	1700.00
at Granville Lake	1976 - 1989	787.77	468.00	1480.00
Churchill River	1960 - 1973	1152.27	665.00	2300.00
at Fidler Lake	1976 - 1989	302.77	40.50	1910.00
Burntwood River	1957 - 1973	118.16	7.79	578.00
at Thompson	1976 - 1989	863.39	340.00	1320.00
Nelson River	1960 - 1973	2490.58	748.00	4992.00
at Kelsey	1976 - 1989	1783.35	418.00	4085.00
Nelson River	1958 - 1973	2391.24	697.00	4620.00
at Bladder	1976 - 1989	1994.48	721.00	4830.00
Levels (m)				
Southern Indian Lake	1964 - 1973	255.19	254.31	256.08
at South Indian Lake	1976 - 1989	257.76	256.94	258.40
Lake Winnipeg	1914 - 1973	217.40	216.01	218.77
at Berens River	1976 - 1989	217.42	216.56	218.14
Cross Lake	1918 - 1973[2]	207.14	205.59	208.85
at Cross Lake	1976 - 1989	206.87	205.06	208.93

[1] 1973-1976 was main LWCN construction period
[2] No Cross Lake record for 1934 - 1949

Figure 2.4 Location of Hydrometric Stations in the FEMP Study Area



WATER FACTS

- Scientists estimate that as much as one-seventh (1/7) of the fresh, liquid surface water in the world is contained within Canada's boundaries.
- Annually, Canada's rivers discharge 9% of the world's renewable water supply - 105 000 cubic metres per second.
- Canada has more lake area than any other country in the world, with 565 lakes larger than 100 square kilometres.
- By area, Lake Winnipeg in Manitoba is the world's twelfth (12th) largest lake with an area of 24 400 square kilometres.
- Canadians are the trustees of almost 25% of all of the world's wetlands, currently covering 14% of the land area of Canada.
- In 1985, the United Nations ranked Canada as the world's largest hydroelectric producer, with 15% of the global output.
- During 1987, 67% of the total power generated in Canada came from hydro sources; in Manitoba, hydro sources provided 94% of total power generated.
- Canada is one of the world's largest dam builders; Canada has built over 600 large dams, and about 60 large domestic interbasin diversions.
- Canada diverts more water than any other country in the world, more than Russia and the United States combined.
- Canada diverts water mostly to concentrate flows for hydroelectric development, especially in northern Quebec and northern Manitoba.

HYDROELECTRIC DEVELOPMENT

Hydroelectric development has had a long history within the Churchill and Nelson rivers drainage area of Manitoba, beginning with the first site developed on the Winnipeg River in 1926. Since then numerous other sites have been developed within this drainage area, both within and outside of Manitoba.

Power generation from hydroelectric sources offers a number of advantages: 1) it is an efficient source of power, with efficiencies typically well above 90% being obtained when hydroelectric power plants are operated at optimum; 2) it is an economic source of power - particularly in a province like Manitoba that has limited fossil fuels to fire thermal power plants; 3) it is a renewable source of energy; and 4) hydroelectric power plants have the ability to respond rapidly and economically to changes in power demand. This latter characteristic is the reason hydroelectric power plants are used to respond to peak power demands and to sudden demands imposed by emergency conditions in the system.

Furthermore, in the past, hydroelectricity had often been promoted as a clean, non-polluting source of energy with inherent environmental advantages over nuclear and fossil-fuel sources. This perception, reflected recently in even leading scientific journals, such as Science, further added to the attractiveness of hydroelectricity.

The hydroelectric potential of the Churchill and Nelson rivers in northern Manitoba was first identified by federal water power surveys in the early 1900s. Extensive provincial surveys beginning in the 1940s confirmed this potential, and hydroelectric feasibility studies commenced. By the mid-1950s the possibility for diversion of the Churchill River flow into the Nelson River basin, via the Rat and Burntwood rivers, had been discovered. In 1961, the Kelsey Generating Station was constructed on the Nelson River, providing 320 MW of power to the International Nickel Company of Canada mine and refinery at Thompson, Manitoba. By 1964, with the assistance of the federal government in the form of a promised 927 km direct current transmission line, it was considered economical to generate Nelson River power for sale to markets in southern Canada and the northern United States. By 1970, when the second generating station had been completed, at Kettle Rapids (1220 MW), it was decided to divert the Churchill River to supplement flows along the lower Nelson River and to build a control structure at the outlet of Lake Winnipeg. A total of nine dam sites on the Nelson River and four on the diversion route were identified.

Control structures at the natural outlet of Southern Indian Lake and at Notigi Rapids on the new diversion route in the Rat River valley, and an excavated channel at South Bay on Southern Indian Lake, were completed in 1976 to facilitate diversion of the Churchill River southward into the Nelson River. The diversion was begun at about one-third of licensed capacity in June 1976 and expanded to full operating discharge in 1977. Construction of works at the outlet of Lake Winnipeg designed to regulate levels on the 24 400 km^2 lake for dependable midwinter flow, begun in 1971, was completed in 1977 with the commissioning of the Jenpeg Control Structure and Generating Station (170 MW). Two more generating stations, Long Spruce (970 MW) and Limestone (1000 MW) have since been built on the lower Nelson River. Currently Manitoba Hydro is seeking authorization to begin construction of the Conawapa Generating Station (1100 MW). The locations of the hydro stations are shown on Map 1 at the back of this volume.

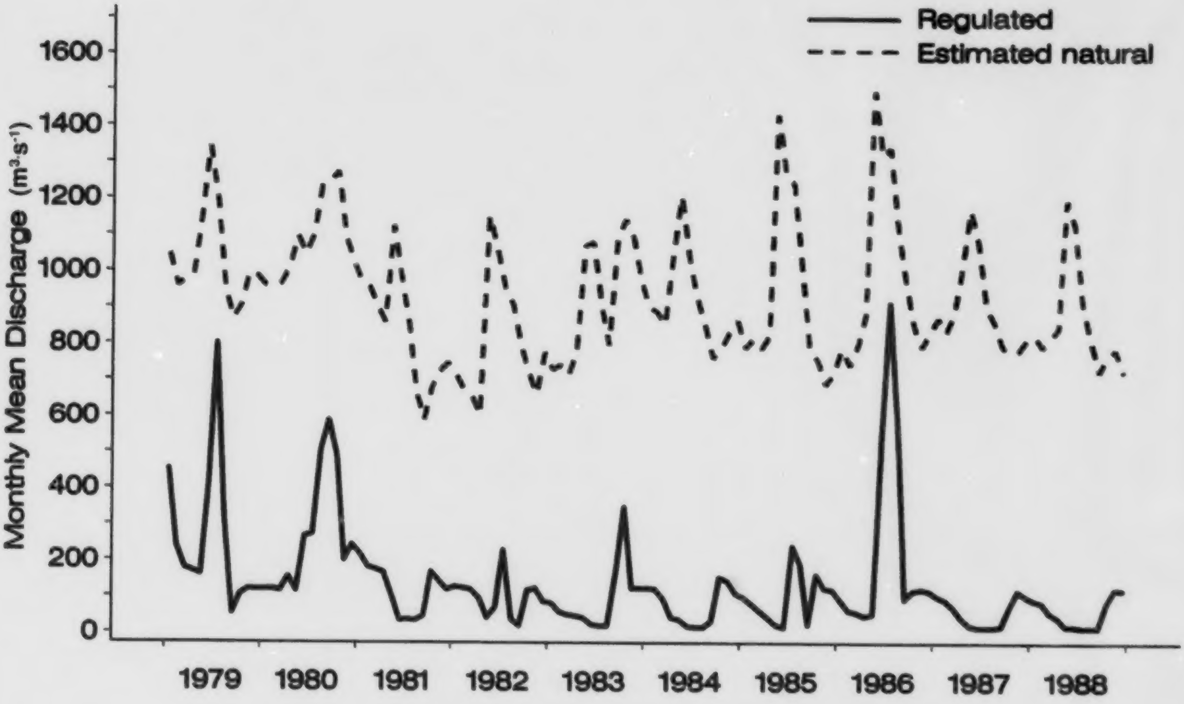
THE CHANGED REGIME

The extensive hydroelectric development within the FEMP study area dramatically altered the water regimes of the Churchill, Nelson, Rat, and Burntwood rivers. The following sections provide an overview of the type and magnitude of these changes, by area. Comparisons are made of river discharge and lake levels under regulated and estimated natural conditions for the period 1979 - 1988. A brief discussion on the ice regime concludes this chapter.

Missi Falls

Missi Falls was the natural outlet of Southern Indian Lake before the Missi Falls Control Structure was built and the Churchill River diverted at Southern Indian Lake. The mean flow of the Churchill River at Missi Falls for the period 1979 - 1988 was 135 $m^3 \cdot s^{-1}$; without diversion it is estimated that the natural flow for this period would have been 925 $m^3 \cdot s^{-1}$ (Fig. 2.5). The long-term mean outflow from Southern Indian Lake is estimated to be about 1100 $m^3 \cdot s^{-1}$, considerably higher than the estimated natural flow for the relatively dry, post-diversion period of the 1980s. A return to wetter conditions and a contin-

Figure 2.5 Regulated and Estimated Natural Monthly Mean Discharge for the Churchill River at Missi Falls, 1979 - 1988



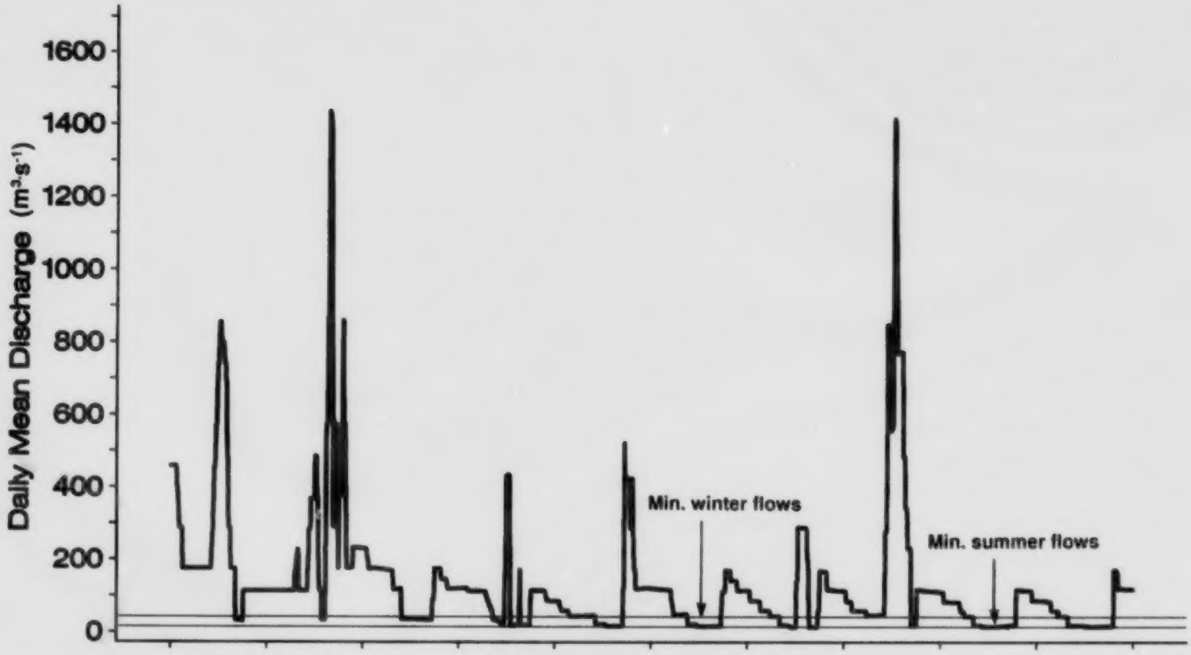
ued adherence to the currently authorized deviations to the diversion operating interim license (allowing up to 963 $m^3 \cdot s^{-1}$ under ice conditions and 991 $m^3 \cdot s^{-1}$ in open water to flow through the Notigi Control Structure) would result in the regulated long-term mean at Missi Dam being close to 200 $m^3 \cdot s^{-1}$.

For the most part, the operating range at Missi Falls, since diversion, has been between 13 and 200 $m^3 \cdot s^{-1}$, with occasional spills to concur with the terms of the interim license regarding high levels on Southern Indian Lake. Without diversion, it is estimated that the natural range of daily discharge at Missi Falls for the period 1979 - 1988 would have been between 600 and 1700 $m^3 \cdot s^{-1}$. In the period 1979 - 1988, there were two years, 1980 and 1986, when the regulated discharge exceeded 1400 $m^3 \cdot s^{-1}$ for a few days; in approximately half of these years, the peak flow was less than about 300 $m^3 \cdot s^{-1}$. Minimum flows each year since diversion have usually been close to the licensed lower limits of 14 $m^3 \cdot s^{-1}$ during the open-water season, and 42 $m^3 \cdot s^{-1}$ during the period of ice cover.

Maximum and minimum discharges are neither at the same season nor of the same duration as before diversion. Under regulation, large peak flows occurred most often during the June to September period but have occurred even in January. The relatively gradual rise and fall of this large river has been replaced by dramatically higher rates of change (Fig. 2.6). A change in discharge of up to 280 $m^3 \cdot s^{-1}$ is allowed in any 24 hour period under the operating license; in practice, this rate was met or exceeded in 1980 and 1986 when discharges at Missi Falls were quickly and briefly raised from under 100 to over 1400 $m^3 \cdot s^{-1}$. In creating the 1980 peak, the daily mean flow was increased by 1400 $m^3 \cdot s^{-1}$ (from 30 to 1430 $m^3 \cdot s^{-1}$) in 16 days in August and dropped by almost 1100 $m^3 \cdot s^{-1}$ (equivalent to the long-term mean flow) in a 7 day period in early September.

Regulation of Missi Falls discharges has had a profound effect on the lower Churchill River. For example, three of the larger lakes along the lower Churchill River, Partridge Breast, Northern Indian, and Fidler, have been reduced in area by 39 to 76%. While not part of the main FEMP study area, some limited study of the effects of the changed water regime along the lower Churchill River was conducted and is reported on in Volume 2 of this report.

Figure 2.6 Daily Mean Discharge for the Churchill River at Missi Falls, 1979 - 1988



Southern Indian Lake

The damming of the natural outlet of Missi Falls raised the water level of Southern Indian Lake by approximately 3 m, and increased the lake's area from 2082 km^2 to 2377 km^2. This change in area of 295 km^2 resulted primarily from the flooding of surrounding land (187 km^2), with the remaining area consisting of the incorporation of nearby lakes by flooding (Fig. 2.7). A composite Landsat image of Southern Indian Lake (Fig. 2.8) illustrates the extent of flooding in the vicinity of the South Indian Lake community.

The original operating license for Southern Indian Lake reservoir stipulated a maximum annual range of 0.6 m; since the early 1980s Manitoba Hydro has annually requested, and received from the province, permission to operate with a range of 1.5 m. In practice, the annual operating range since 1981 has been 1.2 to 1.4 m.

The outflow from Southern Indian Lake that has been diverted from the natural outlet at Missi Falls now exits Southern Indian Lake via a man-made channel that connects the southern end of the lake with the Rat River. Direct measurement of the flows at this man-made outlet had, until recently, not been possible, because site characteristics prevented the use of conventional stream flow measurement techniques. However, recent technological advances have provided a viable alternative means of streamflow measurement at this location (as discussed in chapter 4) and a monitoring site employing this technology has now been established, with financial assistance from FEMP.

Churchill River Diversion Route

The Notigi Control Structure, located about 90 km south of Southern Indian Lake, controls the flows down the Churchill River Diversion (CRD) route. Discharge at the Notigi Control Structure is currently limited by annual operating permits to 991 $m^3 \cdot s^{-1}$ under open water conditions and to 963 $m^3 \cdot s^{-1}$ under ice cover conditions, and is further constrained by licenced limits for water levels in Footprint Lake and for the Churchill River Diversion at Thompson. Between 1979 and 1988, mean flows at Notigi were 825 $m^3 \cdot s^{-1}$ compared to an estimated natural flow for this period of 31 $m^3 \cdot s^{-1}$. (Fig. 2.9).

Figure 2.7 Changes in Lake Surface Areas in the FEMP Study Area

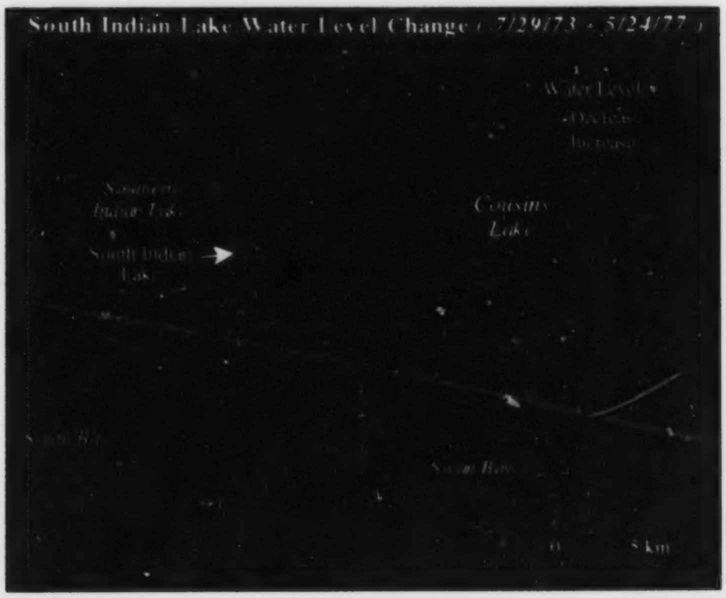
LAKE	Pre-development Areas (km^2)		Post-development Areas (km^2)	Changes in Area (km^2)	
	(1)	(2)	(3)	(4)	(5)
Southern Indian Lake	2082	2190	2377	295	187
Notigi Reservoir	153	182	733	580	551
Churchill River Diversion					
- Wapisu Lake	45.1	46.8	66	20.9	19.2
- Footprint Lake	22.0	62.0	76	54	14
- Threepoint Lake	45.0	46.0	64	19	18
- Upstream of Wuskwatim Lake	4.9	6.2	17	12.1	10.8
- Wuskwatim Lake	50.1	53.2	64	13.9	10.8
- Opegano Lake	7.2	7.2	8	0.8	0.8
- Burr Lake and Wapishtigau Brook	1.4	1.6	6	4.6	4.4
- Birch Tree Lake	5.0	5.8	16	11	10.2
- Mystery Lake	9.0	9.0	12	3	3
- Apussigamisi Lake	14.3	14.3	22	7.7	7.7
TOTAL	204	252.1	351	147	98.9
Outlet Lakes Area					
- Playgreen Lake	691	NA	674	-17	NA
- Little Playgreen Lake	91	NA	89	-2	NA
- Kiskittogisu Lake	273	287	303	30	16
- Kiskitto Lake	173	NA	176	3	NA
- Nelson River above Jenpeg	36.0	36.0	84	48	48
TOTAL*	309*	323*	387*	78*	64*
Kelsey Reservoir					
- Sipiwesk Lake	403	434	496	93	62
- Archibald, Cauchon and Prud'homme lakes	113	124	167	54	43
- Lower Kelsey Reservoir	69	69	101	32	32
TOTAL	585	627	764	179	137
Split Lake	279	NA	280	1	NA
Stephens Reservoir	46	96	288	242	192

Note: Lake surface areas can vary depending on discharge. Lake areas in this table were calculated for discharges that were considered representative for each lake for the pre- and post-development periods.
Area (1): Original area of lake
Area (2): Original area of lake, plus all nearby lakes incorporated by flooding
Area (3): Area of lake after hydroelectric development
Area (4): Change in area of lake, Column (3) - (1)
Area (5): Area of flooded land, Column (3) - (2)
NA: Not Applicable, no increase due to development
*: Kiskittogisu and Nelson River above Jenpeg Dam only

Source: G. McCullough, 1991.

The Notigi Control Structure created a 15 m head and a reservoir with a post-development area of 733 km^2 (Fig. 2.7) Notigi Reservoir was created by incorporating a number of pre-development lakes, such as Karsakuwigamak, Rat and Notigi, with a pre-development surface area of 182 km^2, and by the extensive

Figure 2.8 Composite Landsat Image of Southern Indian Lake


South Indian Lake Water Level Change (7/29/73 - 5/24/77)
Water Level
Decrease
Increase
Southern Indian Lake
South Indian Lake
Cousins Lake
Swan Bay
0
5 km

flooding of terrestrial areas, totalling 551 km^2.

At Thompson, further downstream along the CRD mean flows for the period 1979 to 1988 have been 888 m^3·s^{-1} compared to an estimated natural flow for this period of 93 m^3·s^{-1} (Fig. 2.10). Regulated flows for the post- development period so far have been approximately 9.5 times what would have been the natural flow of the Burntwood River for this period. If the recent deviations authorized to the diversion operating interim license continue, there is a potential for annual mean discharges at Thompson to be approximately 1040 m^3·s^{-1}.

Before diversion, about one-quarter of the annual runoff at both Notigi and Thompson occurred in May and over half in the three months of May, June, and July. Although the annual range at the Notigi Control Structure is now typically between 200 and 500 m^3·s^{-1}, there is no longer any simple seasonal pattern to the rise and fall of the river. The pre-diversion

Figure 2.9 Regulated and Estimated Natural Monthly Mean Discharge for the Churchill River Diversion at Notigi, 1979 - 1988

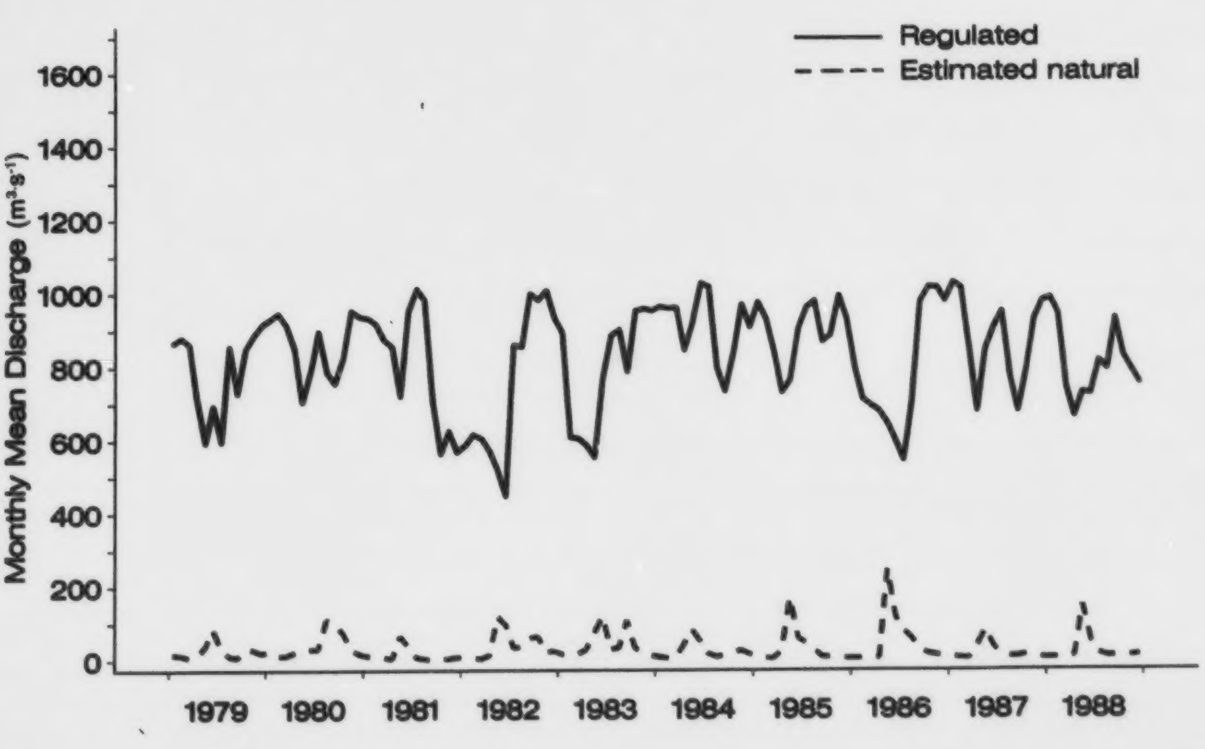
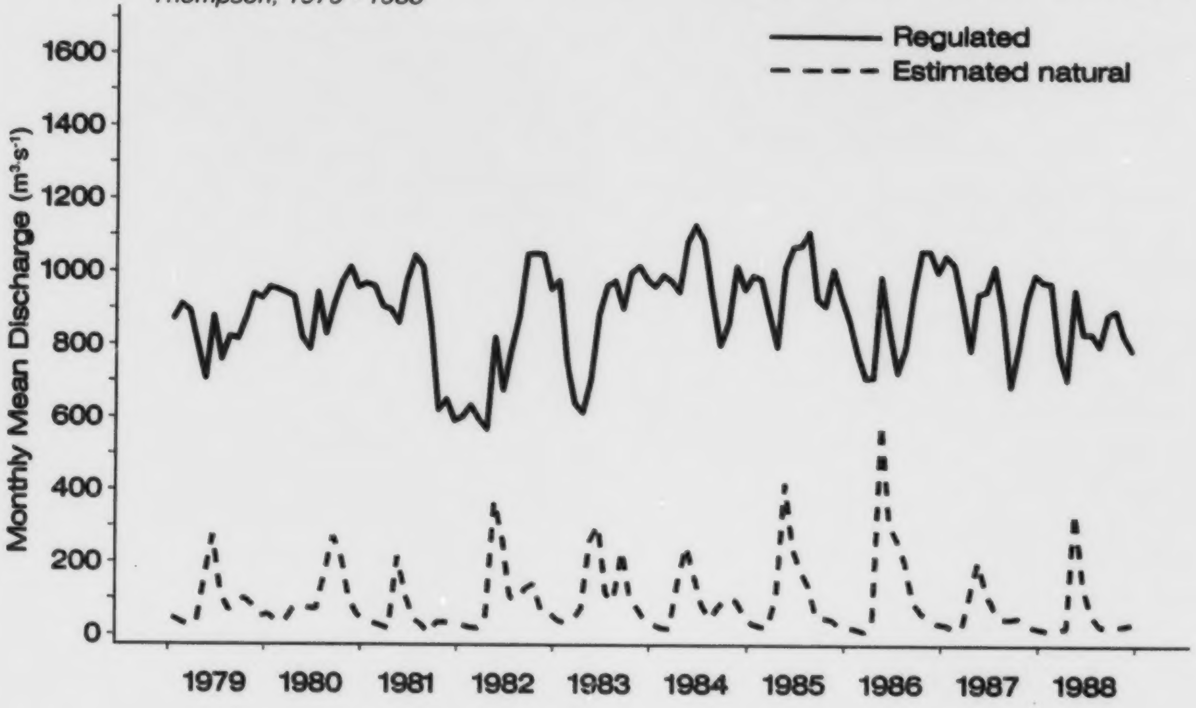


Figure 2.10 Regulated and Estimated Natural Monthly Mean Discharge for the Churchill River Diversion at Thompson, 1979 - 1988



spring runoff peak no longer occurs. The hydrograph of mean daily flows presents a picture not of a river occasionally flooding above a dominant base flow condition, but rather of a river consistently returning to an upper range of 850 - 1000 $m^3 \cdot s^{-1}$ after occasional drops in discharge. While these drops in discharge occur most commonly in March and April, they can occur in any season. The day-to-day range of releases at the Notigi Control Structure have been less than at the Missi Falls Control Structure, with only a few occurrences of a change in discharge greater than 100 $m^3 \cdot s^{-1}$ per day (Fig. 2.11).

The water levels of the lakes and river channels along the CRD reflect the changed flow regime. Examples of the increases in surface areas for some of the lakes along the CRD are given in Fig. 2.7. The most continuous water level record along the CRD has been kept on Footprint Lake at Nelson House. Fig. 2.12 shows the regulated and estimated natural monthly mean lake levels for Footprint and Threepoint lakes. Fig. 2.13 illustrates the extent of flooding at Footprint Lake, as estimated from a composite Landsat image.

Outlet Lakes Area

Lake levels on Lake Winnipeg are controlled by a dam 80 km downstream, at Jenpeg, and several ancillary channels and structures. The 2-Mile Channel was excavated near the natural outlet of Lake Winnipeg to improve the hydraulic efficiency of outflow. A second channel, the 8-Mile Channel, diverts a large but unmeasured proportion of the Nelson River through Kiskittogisu Lake, bypassing the north half of Playgreen Lake. To prevent very widespread flooding of the peatlands to the west, the outlet of Kiskitto Lake into the Channel below Kiskittogisu Lake is dammed, and the drainage from Kiskitto Lake and watershed is diverted north into the Minago River, which reenters the Nelson River below the Jenpeg Dam. The head at Jenpeg Dam is 7.6 m; flooding has been limited mostly to the channel region within 20 km of the dam.

In the 10 year period from 1979 to 1988, the mean flow through Jenpeg Dam was 1505 $m^3 \cdot s^{-1}$ or 82% of 1829 $m^3 \cdot s^{-1}$ flowing via the Nelson River into Cross Lake; the remaining 18%, or 324 $m^3 \cdot s^{-1}$, flowed through Sea River Falls in the East Channel of the Nelson River. The annual mean regulated flow for this period was not significantly different from what it would have been under estimated

Figure 2.11 Daily Mean Discharge for the Churchill River Diversion at Notigi, 1979 - 1988

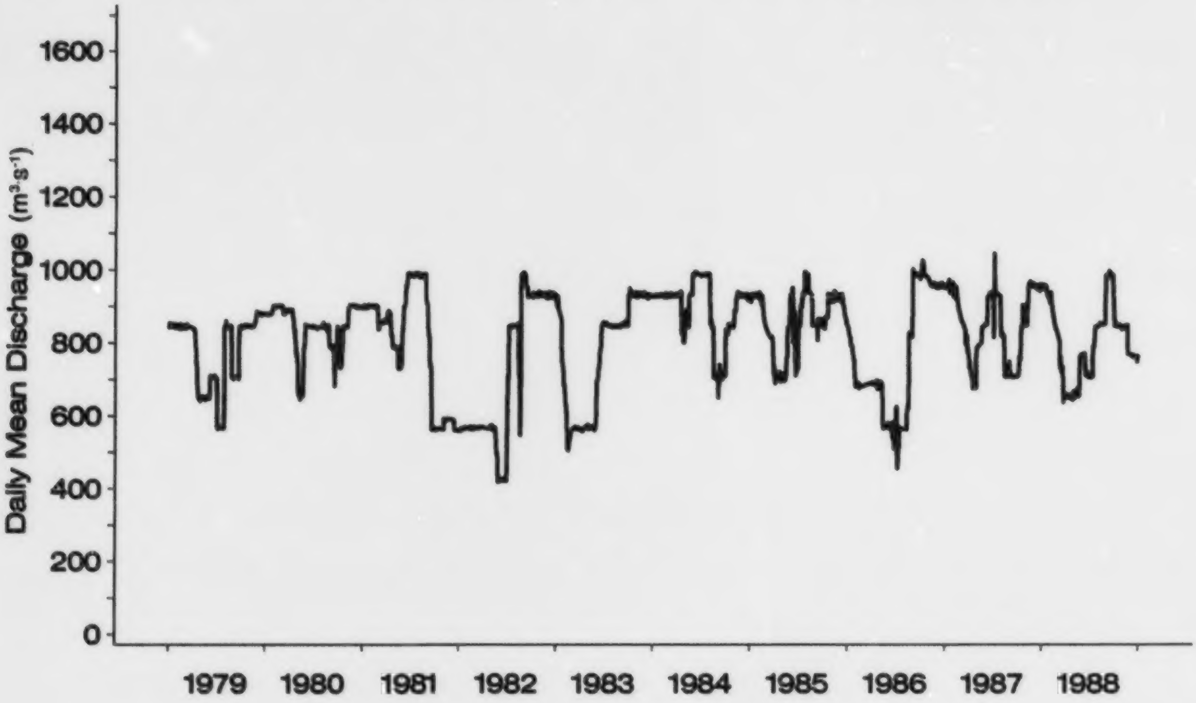


Figure 2.12 Regulated and Estimated Natural Monthly Mean Level for Footprint and Threepoint Lakes, 1979 - 1988

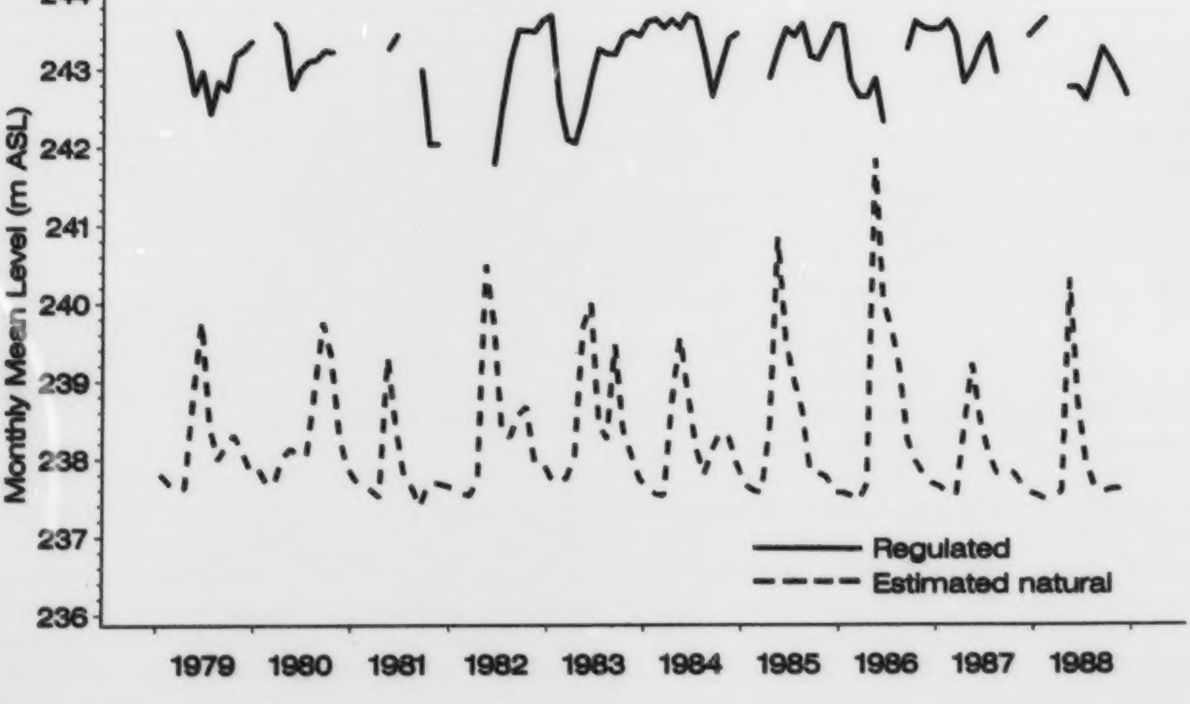
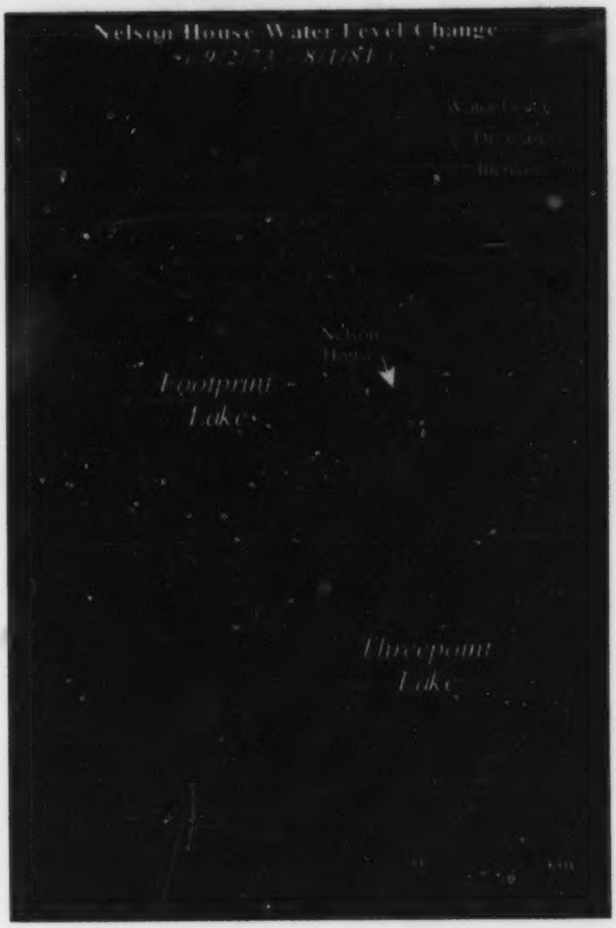


Figure 2.13 Composite Landsat Image of Footprint Lake



natural flow conditions for this same period. However, the flow for this period was considerably less than the long-term mean Nelson River flow at these stations of about 1975 $m^3 s^{-1}$, since, as noted previously, the 1980s were a dry decade in comparison to the long-term record. The effect of the altered flow regime on the surface areas of the Outlet Lakes is shown in Fig. 2.7.

The seasonal distribution of the flows in the Outlet Lakes region, and through the rest of the Nelson River, has been dramatically different than what it would have been if it had not been regulated at Jenpeg Dam. Without regulation, the peak flows of the Nelson River into Cross Lake would have occurred most commonly in June or July. Since 1979, the peak flow has occurred between October and December except during the summers of 1979 and 1986 when water had to be released at Jenpeg to prevent unusually high runoff from raising Lake Winnipeg above its natural range. For the period 1979 to 1988, the mean June - August discharges into Cross Lake were 670 - 770 $m^3 s^{-1}$ lower than they would have been under estimated natural conditions for this period. In the December to February period, they were 520 - 750 $m^3 s^{-1}$ higher than natural (Fig. 2.14).

The water level of Cross Lake reflects the changed flow regime, as shown in Fig. 2.15. The seasonal level fluctuations have been strongly reversed, causing 300 km^2 of lake bottom to be intermittently dewatered. (The area of Cross Lake, from 1979 - 1988, varied from under 300 km^2 to over 600 km^2.) The Landsat image shown in Fig. 2.16 shows the dewatered Cross Lake in the summer of 1984. A composite Landsat image for the Norway House area is shown in Fig. 2.17.

Nelson River

Four dams have been built to-date on the lower Nelson River - Kelsey Dam, located upstream of Split Lake, and 3 dams downstream of Split Lake - Kettle, Long Spruce, and Limestone. (A composite Landsat image for Split Lake is shown in Fig. 2.18.) Kelsey Dam impounded the river 16 m at the forebay, causing extensive flooding reaching upstream 150 km to Sipiwesk Lake, which was raised 1 to 2 m. The extent of the flooding caused by Kelsey Dam, as illustrated by changes in lake surface areas, is shown in Fig. 2.7. The monthly mean discharge record at Kelsey Dam (Fig. 2.19) shows seasonal shifts of magnitudes similar to those at Cross Lake.

Kettle Dam, with a forebay head of 30 m, created the new 288 km^2 Stephen's Reservoir, flooding approximately 242 km^2 beyond the pre-development Nelson River's channel (Fig. 2.7). Long Spruce and Limestone dams, each with a 24 m head, are run-of-the-river impoundments generally within high riverbanks and consequently have not caused major flooding.

At Kettle Dam, the first of the series of lower Nelson River dams where flows have been augmented by the addition of the diverted Churchill River flows, the mean discharge for the period 1979 to 1988 has been 2980 $m^3 s^{-1}$, 37% more than the 2170 $m^3 s^{-1}$ that it would have been without the Churchill River Diversion (Fig. 2.20). The long-term mean flow at Kettle, without diversion, has been computed to be 2276 $m^3 s^{-1}$. Given the current operating regime, limited by regular deviations to the interim license, there is a potential for diversion of 940

Figure 2.14 Regulated and Estimated Natural Monthly Mean Discharge for the Nelson River at Jenpeg and Sea River Falls, 1979 - 1988

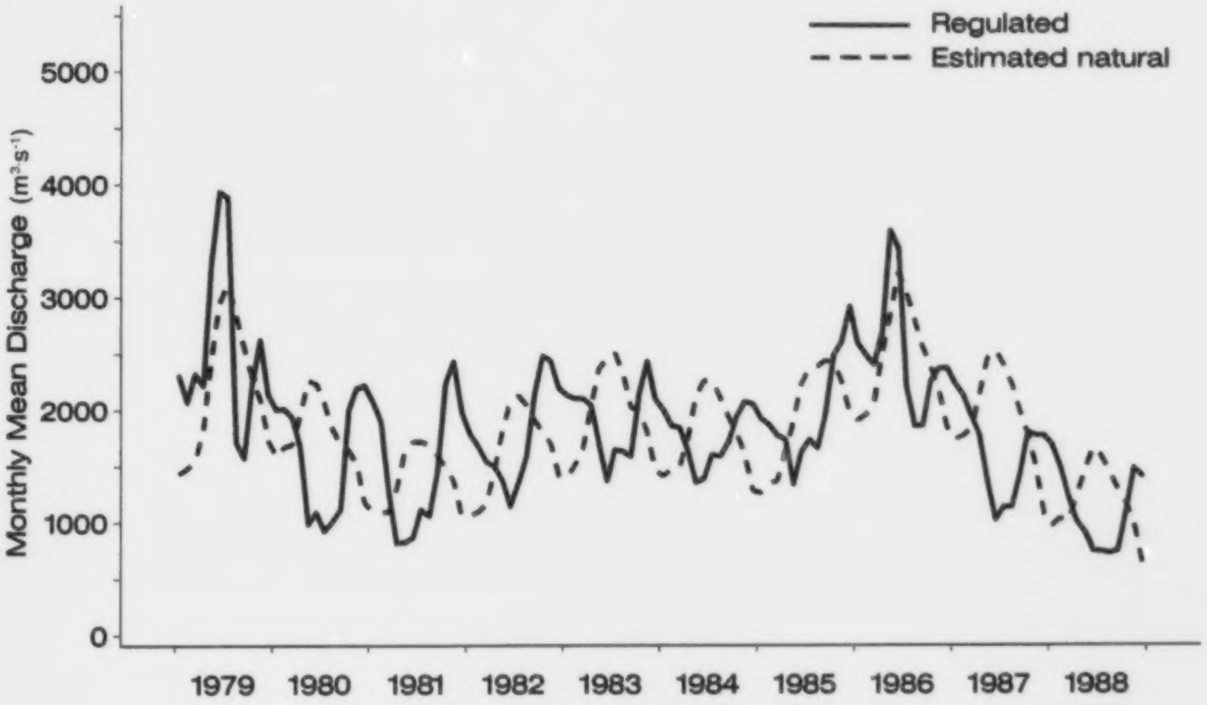


Figure 2.15 Regulated and Estimated Natural Monthly Mean Level for Cross Lake, 1979 - 1988

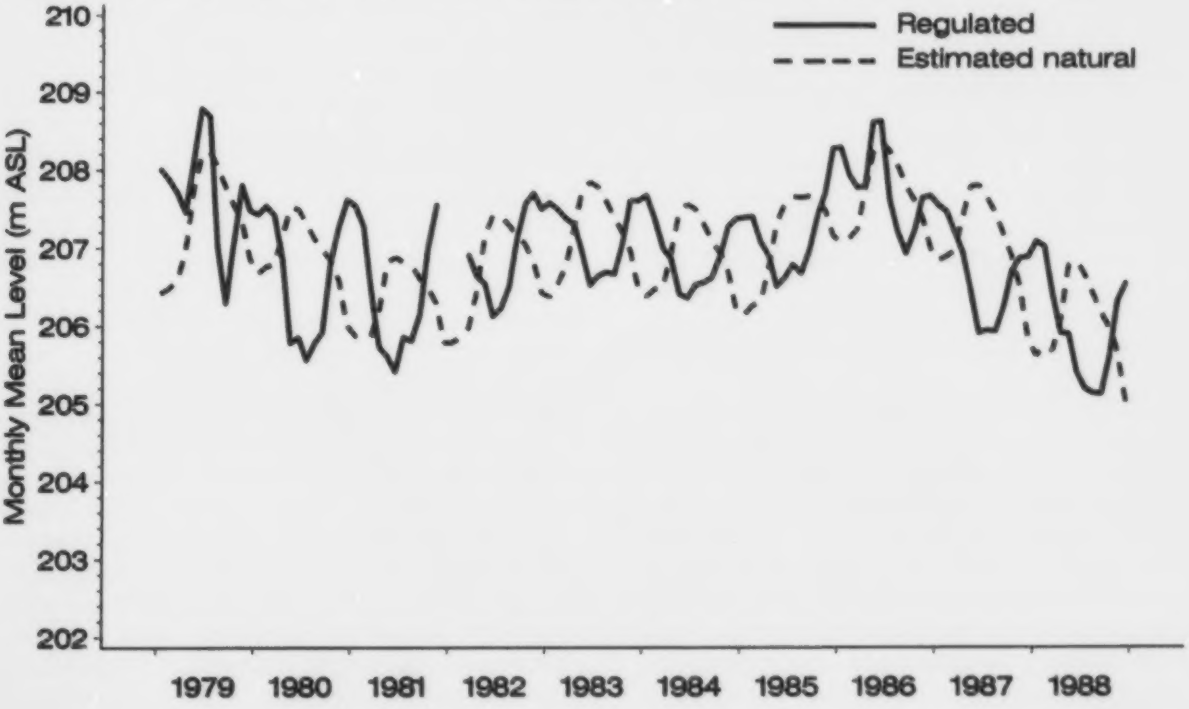


Figure 2.16 Landsat Image of Cross Lake, 1984

Cross Lake Water Level Change(6/15/84)
Cross Lake
Cross Lake
Pipestone Lake
0
15 km

Figure 2.17 Composite Landsat Image of Norway House Area

Norway House Water Level Change
(6/29/75 - 8/4/85)
Little Playgreen Lake
Norway House
Playgreen Lake

m³·s⁻¹ into the Nelson River above Split Lake. Hence, the long-term mean will more likely be near 3220 m³·s⁻¹ or about 8% higher than the mean post-diversion flow so far.

Without regulation at Jenpeg Dam and the diversion of the Churchill River, the lower Nelson River would have peaked in May or June, at flows from 1000 to over 2200 m³·s⁻¹ above the low flows of the previous January

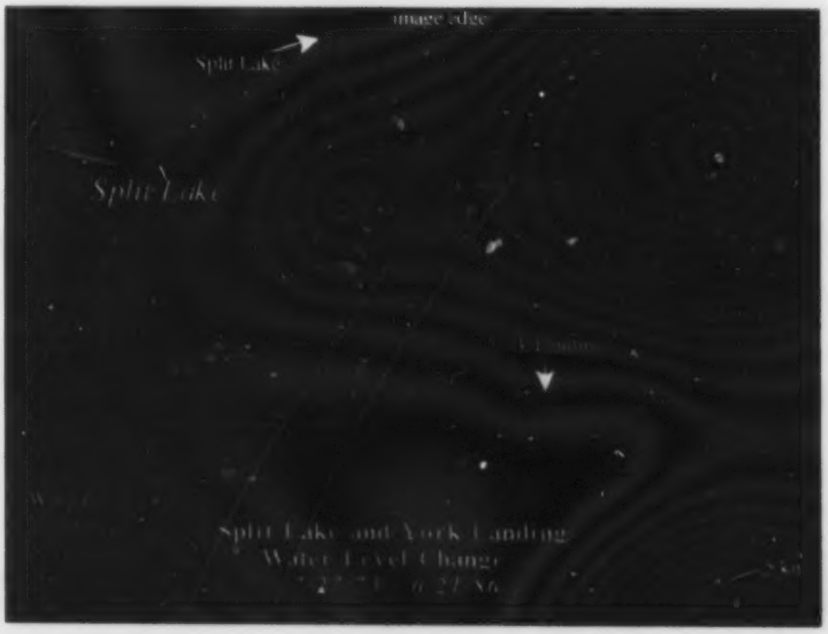


image edge
Split Lake
Split Lake
Split Lake and York Landing
Water Level Change

Figure 2.18 Composite Landsat Image of Split Lake

Figure 2.19 Regulated and Estimated Natural Monthly Mean Discharge for the Nelson River at Kelsey Dam, 1979 - 1988

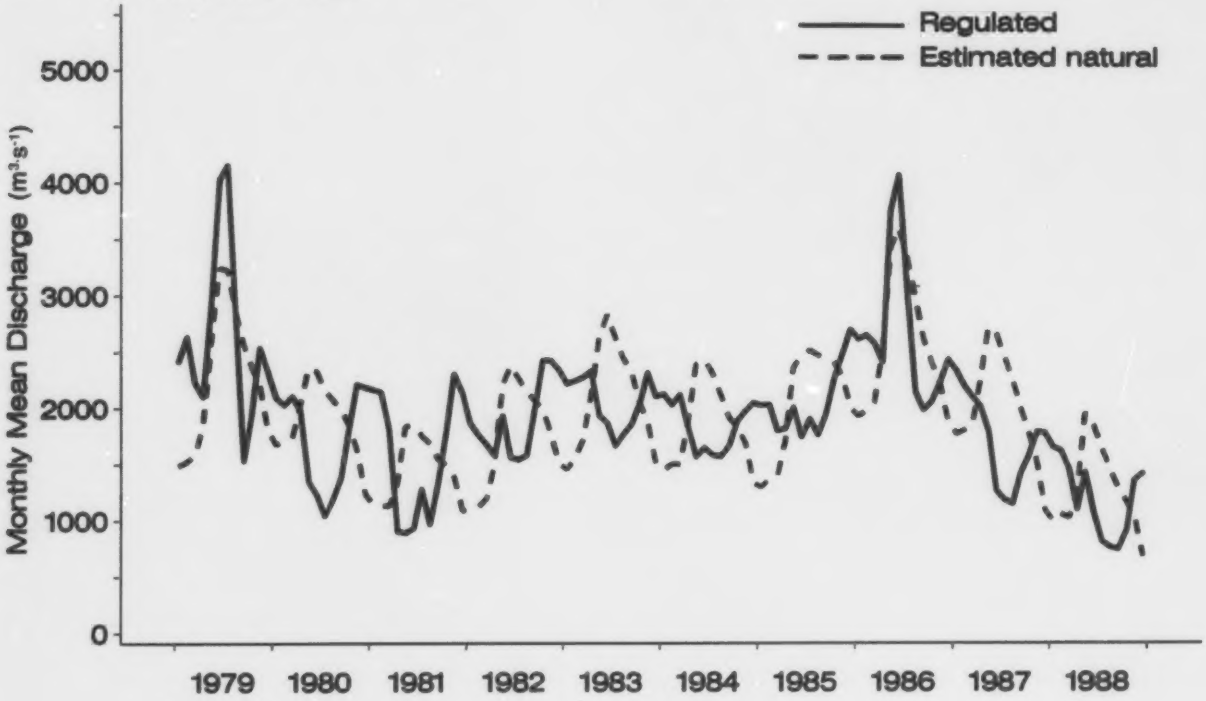
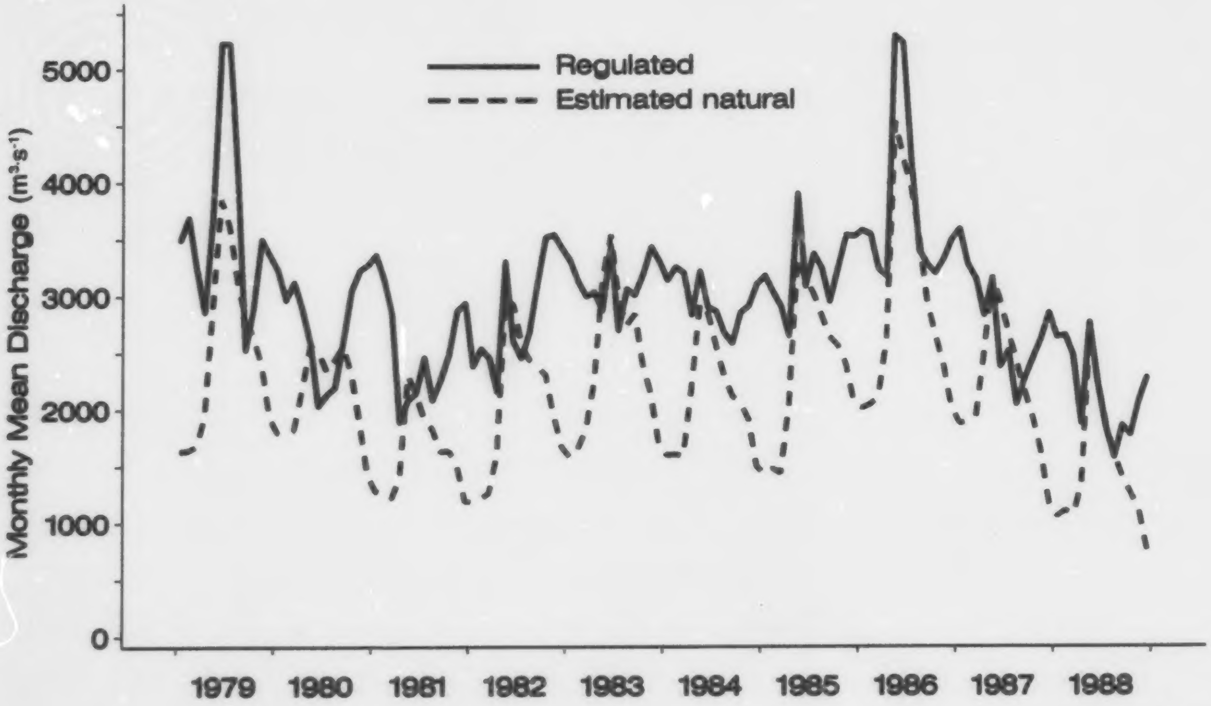


Figure 2.20 Regulated and Estimated Natural Monthly Mean Discharge for the Nelson River at Kettle Dam, 1979 - 1988



or February. Under the regulated regime the annual peak discharge typically has occurred from November to January, although exceptions were common. The 1979 and 1986 high releases at Jenpeg Dam produced major spring peaks at Kettle Dam, with flows in both years over 5000 $m^3 \cdot s^{-1}$. Much smaller, and very brief, spring peaks were due to local and diversion flows.

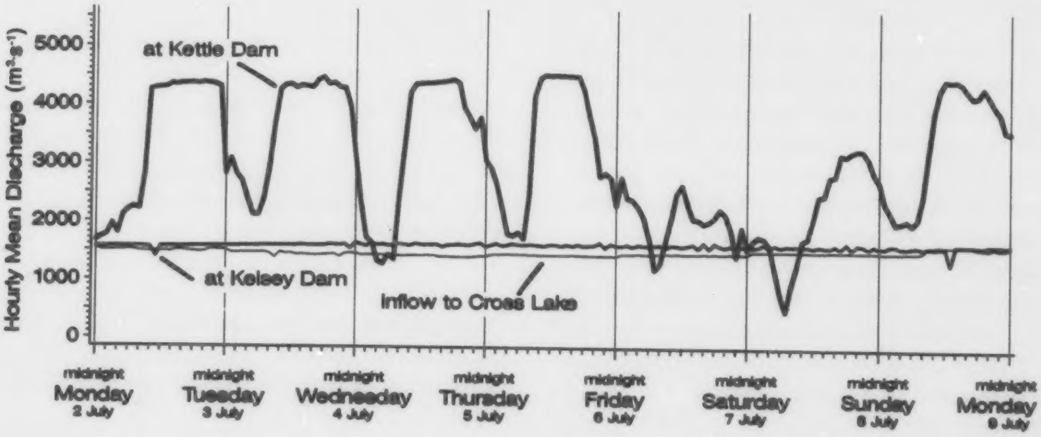
Despite the reversal of the seasonal pattern of the lower Nelson River flows, the diverted Churchill River water has caused even the regulated low summer flows to be as high as, or higher than, what they would have been otherwise. Mean June to August flow has on average been approximately 190 $m^3 \cdot s^{-1}$ more than without regulation and diversion, while the mean for December to February has been 1610 $m^3 \cdot s^{-1}$ higher.

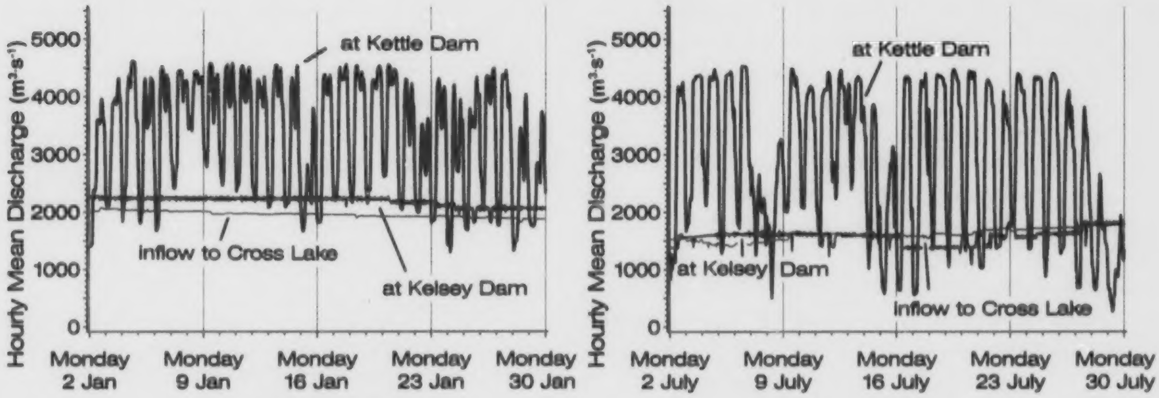
It is interesting to note here that the overall effect of the regulation of the Churchill and Nelson rivers for hydroelectric production has been to reduce the amount of water delivered to Hudson Bay in the open-water period. For the period 1979 to 1988, it is estimated that, under natural conditions, an average of 47 km^3 would have flowed past Missi Falls and Kettle Rapids from June through October each year; under regulation, this was reduced by 15% to 40 km^3. The difference of 7 km^3, 7% of the combined annual delivery to Hudson Bay of the Churchill and Nelson rivers, has been shifted to the ice-covered months of November to May.

Perhaps the most dramatic effect of regulation on the lower Nelson River flows can be seen in the day-to-day regime. At Kettle Dam, for the period 1979 - 1988, most of the day-to-night drops in hourly mean discharge were over 2000 $m^3 \cdot s^{-1}$ in winter, and were commonly almost 3000 $m^3 \cdot s^{-1}$ in summer. Upstream at Kelsey and Jenpeg dams, such large day-to-day fluctuations never occurred. The maximum 24 hour change in daily mean discharge was less than 1000 $m^3 \cdot s^{-1}$. Such large day-to-day fluctuations are not the norm even for a large river like the Nelson. For example, the largest 24 hour change in daily mean flow at Bladder Rapids, below Cross Lake, for the pre-development period 1959 to 1974 was under 400 $m^3 \cdot s^{-1}$.

The variability in the short-term discharge on the lower Nelson River is tied to the weekly pattern of energy usage by Manitoba Hydro consumers. In general, discharge at Kettle Dam, and all downstream dams, is quickly raised each morning to coincide with the beginning of the working day (Fig. 2.21). High discharges are maintained until late afternoon or evening, when the discharge is dropped back down to a daily low in the early hours of the morning. After the Friday night drop, the discharge fluctuates at low values throughout most weekends, only to be raised back to weekday levels on Monday morning.

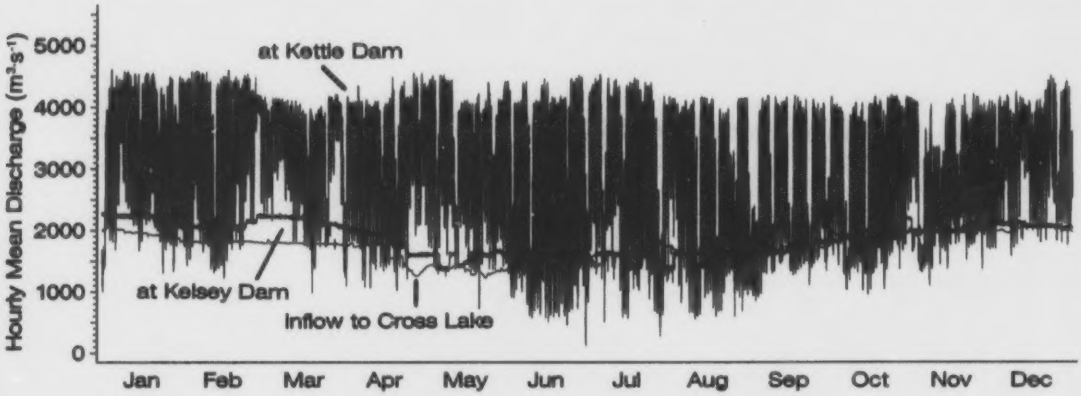
Figure 2.21 Hourly Mean Discharge for the Nelson River, 1984 . . . continued next page





January

July



Ice Regime

The long, cold winters that are experienced in the FEMP study area means that for a substantial part of each year, the lakes and rivers of the Lake Winnipeg, Churchill and Nelson rivers system are ice covered. As illustrated in Figs. 2.22 to 2.25, the ice cycle is governed by: 1) meterological conditions, such as air temperature, precipitation, and wind; 2) hydrologic conditions, such as water temperature, velocities, and levels; and 3) by lake and river morphology, such as shoreline configuration, water depths, and natural and man-made obstructions. In particular, it is the inter-relationships of these three major factors that determine the progress of the ice cycle from freeze-up to break-up.

The linear chain of events shown in Fig. 2.22 is by necessity a simplification; in nature, the cycle proceeds through a series of feedbacks. For example, during the freeze-up period, the actual development and persistence of a complete ice cover can take a relatively long time, with repetitive periods of freezing and thawing, even to the point of no ice cover.

It should also be noted that not all of the sequences shown in Fig. 2.22 occur on all the lakes and rivers in the FEMP study area. For example, an ice skim can only form under very quiet, windless conditions, such as on small shallow lakes or in the bays and inlets of larger lakes. Under such conditions, the skim can form across the whole surface of a lake overnight and then thicken through the growth of black ice and possibly snow ice. This type of freeze-up could occur in the still-water areas of the larger lakes and reservoirs of the FEMP study area (e.g. Notigi Reservoir), but would be unlikely on the smaller lakes and central areas of the larger water bodies, due to their riverine nature.

The influence of man-made factors, such as hydroelectric dams and river regulation, on the ice cycle is clearly shown in Figs. 2.23 to 2.25. For example, ice conditions on those river stretches upstream of a dam differ from those found downstream of a dam. The presence of a dam defines the lodgement point for that stretch of river, delaying the freeze-up downstream of the dam and advancing the freeze-up for some distance upstream of the dam. During winter, slush ice may be a problem downstream of the dam, while upstream of the dam, very irregular ice cover near the riverbanks may occur as a result of reservoir fluctuations. In the spring, the stretch of river downstream of a dam may experience a quiet thermal break-up of ice, while upstream ice jams may occur which, with high spring discharges, can cause extensive flooding.

As noted in the previous sections, one common characteristic of the regulated river regime is the large fluctuations that now can occur in comparison to what was the norm under natural flow conditions. Unlike open water conditions, monthly or even daily measurements of water levels and velocities may be insufficient to characterize the condition of lakes and rivers under ice cover. Short-term fluctuations, which in the FEMP study area can sometimes occur hourly, can have a dramatic effect on the ice cover. In particular, under-ice currents can result in thin ice that diminishes the strength and stability of the ice cover (Fig. 2.24).

The ice regime is both affected by and can cause physical changes to the environment. Examples of the latter include the scouring of shorelines by the movement of large, thick ice sheets; the gouging of river beds by the keels of moving ice sheets containing pressure ridges; and the occurrence of floods due to ice jams.

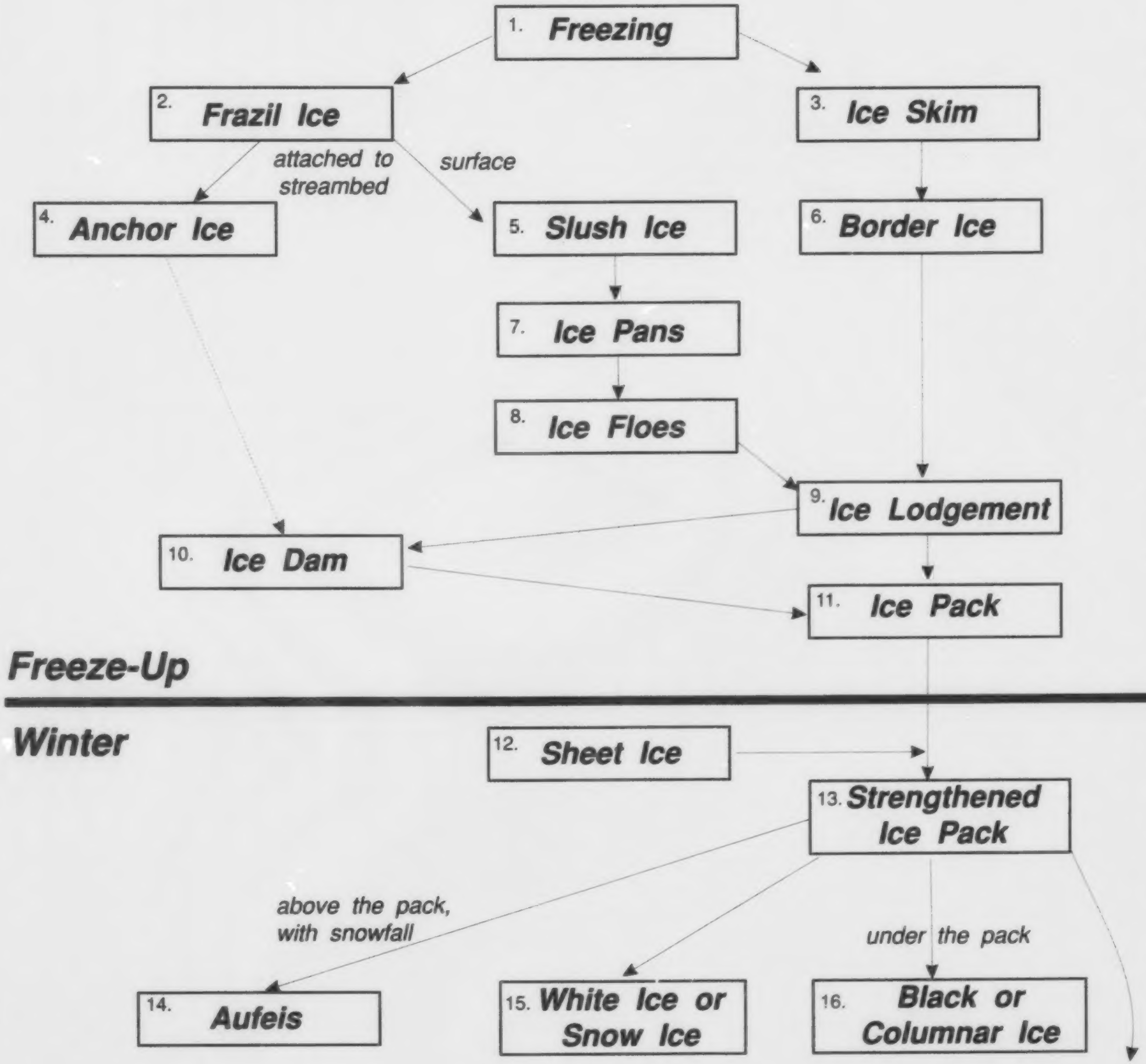
Physical changes to and by the ice regime can have a profound effect on the wildlife and people who live near and are dependent on the area's water resources. Perhaps, the most pervasive effect of changes to the ice regime is the effect on transportation. Over-ice transportation, or the trafficability of the ice, is dependent upon the weight bearing capacity of the ice (see Fig. 2.26) and upon surface ice conditions, such as the presence of slush ice and pressure ridges. Surface ice conditions are also particularly important to recreational uses of ice, such as ice skating and dog sledding. In addition, wildlife harvesting, whether for income, food, or recreational purposes, can be impeded by changes in the ice cover.

Fish and wildlife can be directly affected by changes in the ice regime in a number of ways. For instance, a change in water levels and consequently a change in ice cover can expose the eggs of fall spawners, such as whitefish, to fatal temperatures, while delayed breakup can delay the spawning activity of spring spawners, such as pike. Fish may also be affected if increased frazil ice production in large open water areas is sufficient to block fish gills. Large open water areas, which are characteristic of river stretches downstream of a hydro plant, can be beneficial to some animals such as otter and mink, which exhibit a preference for natural open water areas; however, such areas may interfere with the migration paths of moose and other ungulates.

Developing a detailed understanding of the ice regime over the large FEMP study area and of the changes to it since the hydroelectric projects was considered to be beyond the scope of the FEMP. However, it is evident that a significant feature of the changes to the ice regime is that a reasonably consistent and predictable natural cycle has been replaced by an unnatural one - one that will be difficult to predict, in part because it will be dependant upon the future power demand requirements.

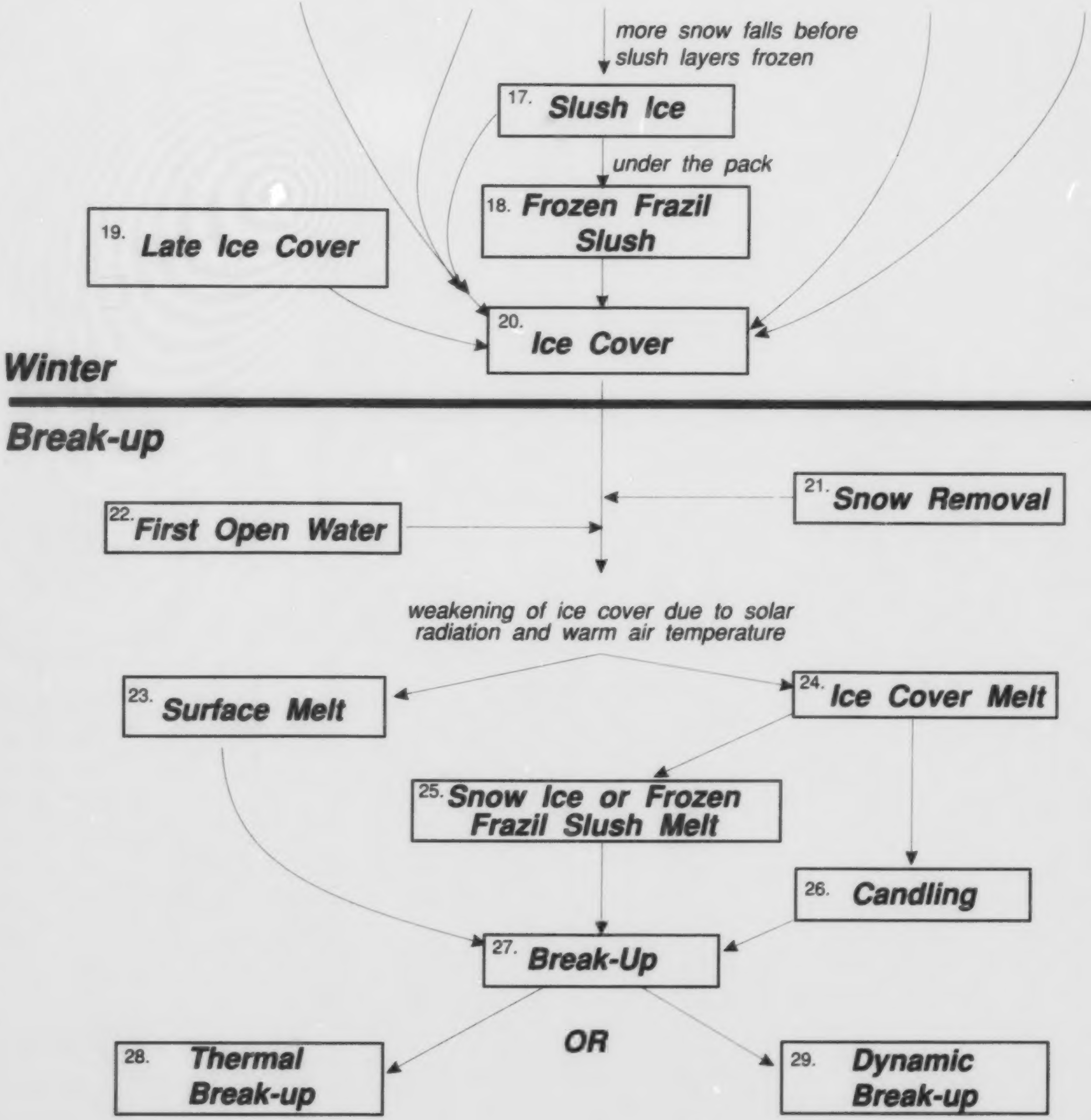
Some predictive ability may be possible with respect to the important issue of changes in ice cover thickness, if detailed bathymetry were available to relate to water level records and most importantly if some form of very accurate sub-surface temperature monitoring could be achieved. The possibility of setting up a forecast - monitoring program for critical transportation routes could be investigated; however, the intensive information requirements to develop such a forecast preclude its application for large-scale regions, if reasonable accuracy of forecast is desired.

Figure 2.22 The Ice Cycle


1. Freezing
2. Frazil Ice
3. Ice Skim
attached to streambed
surface
4. Anchor Ice
5. Slush Ice
6. Border Ice
7. Ice Pans
8. Ice Floes
9. Ice Lodgement
10. Ice Dam
11. Ice Pack
Freeze-Up
Winter
12. Sheet Ice
13. Strengthened Ice Pack
above the pack, with snowfall
under the pack
14. Aufeis
15. White Ice or Snow Ice
16. Black or Columnar Ice

1. Water temperature reaches 0°C
2. In turbulent areas, small particles of ice form
3. In very quiet areas, a skim of ice forms
4. Frazil deposits form on streambed
5. Particles eventually reach surface forming slush ice
6. Ice grows in thickness and laterally
7. Congeals in cold temperatures to form ice pans
8. Pans meld together to form large ice floes
9. Ice floes and border ice joining to form ice pack
10. Ice may accumulate beneath to form a freeze-up dam
11. Pack will advance upstream, occasionally may collapse reducing in length, but increasing in thickness

12. Sheet ice may form in interstices of ice pack
13. Increased pack strength
14. Under certain conditions, water is forced onto top of ice pack and freezes
15. Slush layer, caused by water from cracks saturating lower snow layer, is subsequently frozen
16. Freezing of water under the pack through the growth of candle-like crystals



more snow falls before slush layers frozen
17. Slush Ice
under the pack
18. Frozen Frazil Slush
19. Late Ice Cover
20. Ice Cover
Winter
Break-up
21. Snow Removal
22. First Open Water
weakening of ice cover due to solar radiation and warm air temperature
23. Surface Melt
24. Ice Cover Melt
25. Snow Ice or Frozen Frazil Slush Melt
26. Candling
27. Break-Up
OR
28. Thermal Break-up
29. Dynamic Break-up

17. Several layers of slush and thin solid ice layers
18. Any slush ice under ice pack will be incorporated into ice cover as it thickens
19. Formation of late ice cover over open water, eg. rapids

21. Snow cover on ice melts
22. Open water appears first in areas of thin or late ice
23. Melting of ice at surface (slow process)
24. Melting within ice cover
25. Melting of snow ice or frozen frazil slush, takes very much longer to decay
26. Melting of columnar ice producing candle-like separate columnar grains; structural decay and decrease in strength
28. Ice cover melts in place
29. Movement of ice fragments and water downstream; if movement is the result of an ice jam release, flood waves can occur

Figure 2.23 Freeze-Up Concerns

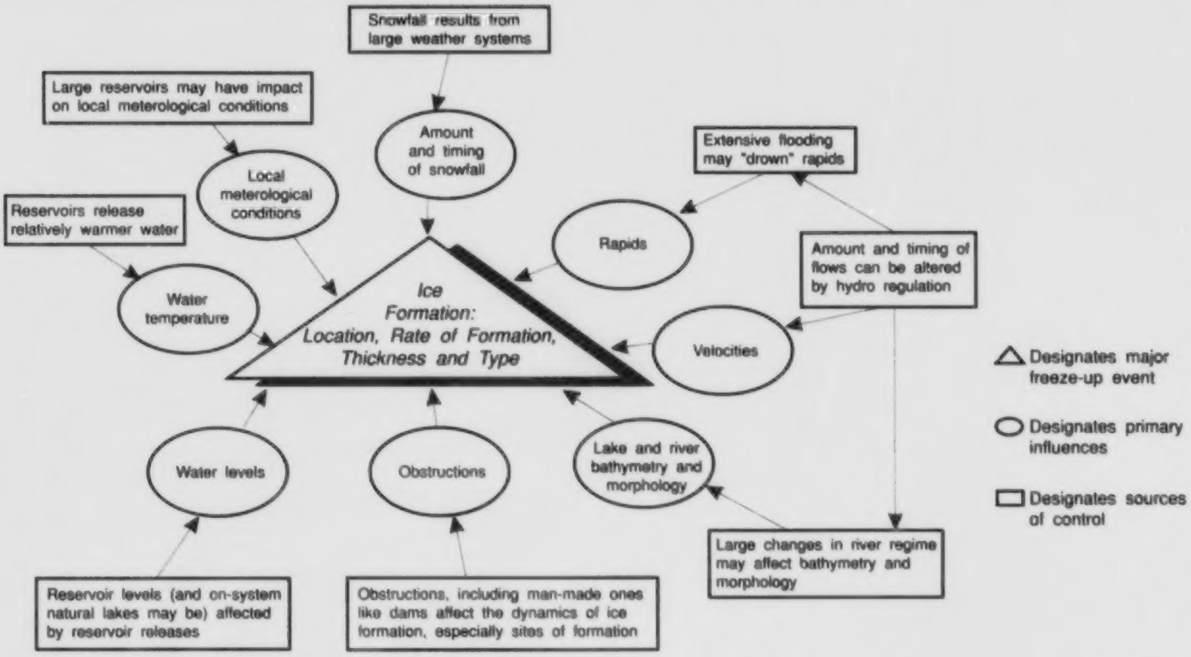

Snowfall results from large weather systems
Large reservoirs may have impact on local meterological conditions
Amount and timing of snowfall
Extensive flooding may "drown" rapids
Local meterological conditions
Reservoirs release relatively warmer water
Rapids
Amount and timing of flows can be altered by hydro regulation
Ice Formation: Location, Rate of Formation, Thickness and Type
Water temperature
Velocities
Designates major freeze-up event
Designates primary influences
Designates sources of control
Water levels
Obstructions
Lake and river bathymetry and morphology
Large changes in river regime may affect bathymetry and morphology
Reservoir levels (and on-system natural lakes may be) affected by reservoir releases
Obstructions, including man-made ones like dams affect the dynamics of ice formation, especially sites of formation

Figure 2.24 Winter Ice Concerns

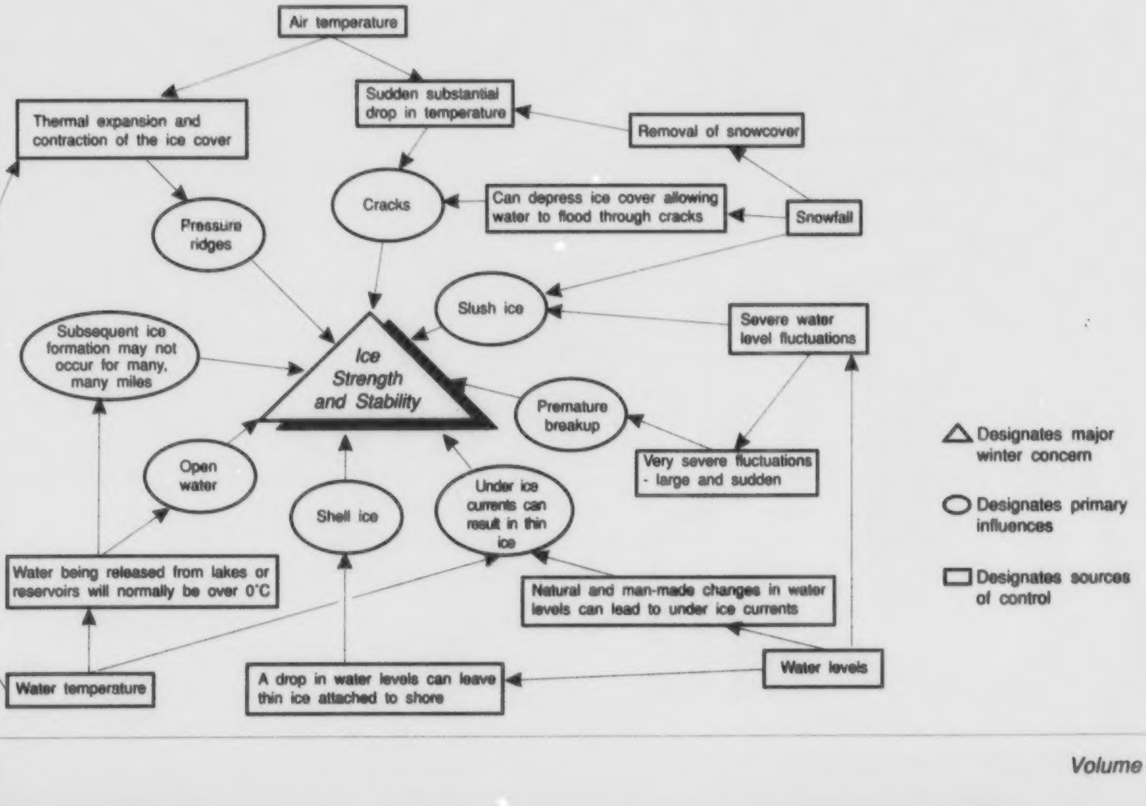

Air temperature
Sudden substantial drop in temperature
Thermal expansion and contraction of the ice cover
Removal of snowcover
Cracks
Can depress ice cover allowing water to flood through cracks
Snowfall
Pressure ridges
Slush ice
Severe water level fluctuations
Subsequent ice formation may not occur for many, many miles
Ice Strength and Stability
Premature breakup
Designates major winter concern
Very severe fluctuations - large and sudden
Open water
Shell ice
Under ice currents can result in thin ice
Designates primary influences
Water being released from lakes or reservoirs will normally be over 0°C
Natural and man-made changes in water levels can lead to under ice currents
Designates sources of control
Water temperature
A drop in water levels can leave thin ice attached to shore
Water levels

Figure 2.25 *Break-Up Concerns*

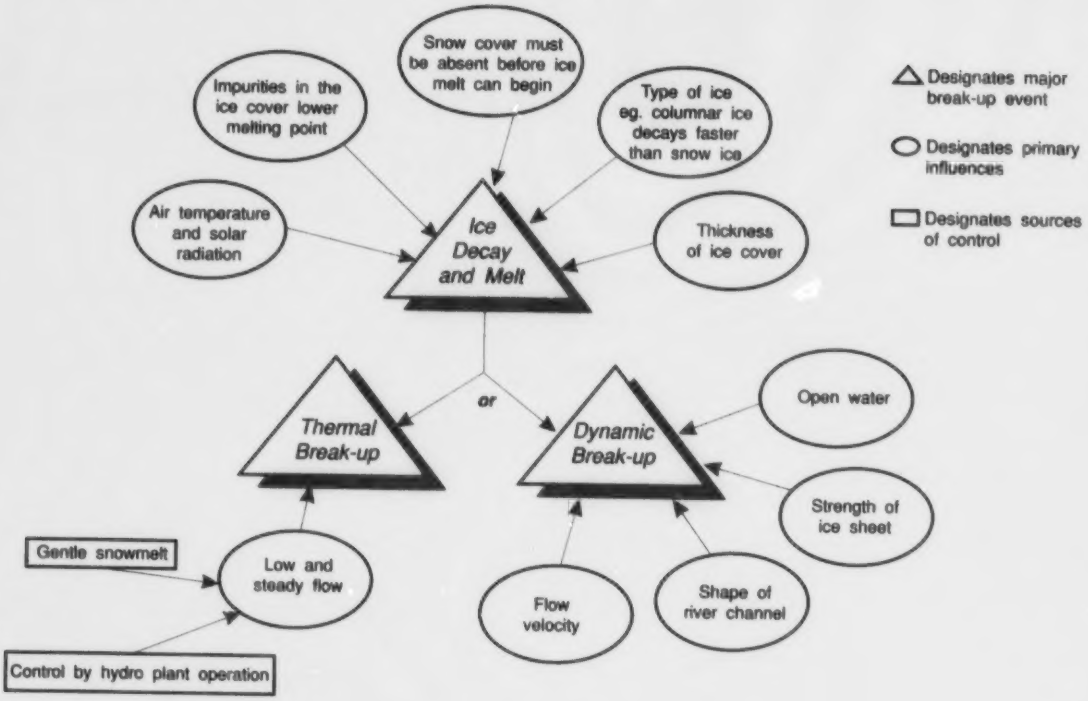
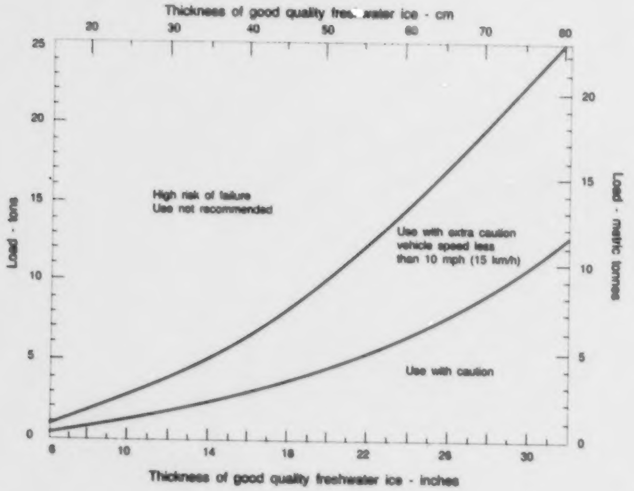

Snow cover must be absent before ice melt can begin
Impurities in the ice cover lower melting point
Type of ice eg. columnar ice decays faster than snow ice
Air temperature and solar radiation
Ice Decay and Melt
Thickness of ice cover
or
Thermal Break-up
Dynamic Break-up
Open water
Strength of ice sheet
Gentle snowmelt
Low and steady flow
Control by hydro plant operation
Flow velocity
Shape of river channel
△ Designates major break-up event
○ Designates primary influences
▭ Designates sources of control

Figure 2.26 *Weight-Bearing Capacity of Ice*



SUMMARY

The natural regime of the Churchill and Nelson, Rat and Burntwood rivers has been dramatically, and perhaps irrevocably, altered by hydroelectric development. The diversity and magnitude of the changes in river flows and lake levels are summarized on Map 2 at the back of this volume.

The greatest perturbations to the water regime occurred during and immediately after the construction period of the early to mid-1970s. Future, although smaller, perturbations can be expected as continued adjustments are made to Manitoba Hydro's operating regime and as future hydro dams are constructed and put into operation. Over time, the water regime will become stabilized and achieve a new steady state, albeit one that will be considerably different from the natural regime which existed before the LWCN project.

CHAPTER 3

PLANNING FEMP

The Federal Ecological Monitoring Program (FEMP) was planned within the framework of the historical, legal, political, socioeconomic, and environmental conditions that existed at the time. The intent of this chapter is to briefly describe these conditions that collectively determined FEMP.

NORTHERN FLOOD AGREEMENT

The governments of Canada and Manitoba, recognizing the overall interest and conflict over the use of the water and related resources in the LWCN Hydroelectric Project area, initiated the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Study in 1971. The objective of this four-year study was to determine the effects that the regulation and diversion projects were likely to have on water and related resource uses and to make recommendations for enhancing the overall benefits with due consideration for the protection of the environment. One of the 47 recommendations (Rec. #10) of this study was "that appropriate government departments and agencies develop and implement a long term coordinated ecological monitoring and research program to allow impact evaluations and to assist in the ongoing management of the affected area".

In 1976 and 1977, detailed proposals were formulated for multi-discipline, multi-agency, coordinated ecological monitoring programs which would address LWCN Study Rec. #10 (Hecky et al. 1976; JIAWG 1977). These proposals were never implemented, largely because of the signing, in 1977, of a landmark agreement called the Northern Flood Agreement (NFA).

The NFA is an open-ended, open-funded, legally binding contract signed by Canada, Manitoba, Manitoba Hydro, and the Northern Flood Committee (NFC) - an organization representing the five Indian bands whose members live on reserves in the LWCN Hydroelectric Project area - Nelson House, Split Lake, York Factory, Cross Lake and Norway House. The objective of the NFA is to ensure that all persons represented by the NFC who are adversely affected by the LWCN Hydroelectric Project receive fair and equitable treatment.

The NFA contains twenty-five articles and eight appendices dealing with a range of topics including land exchange, community infrastructure, employment, and environmental impacts. Two articles of particular relevance to FEMP are Article 17.5 which states: "In particular but without limitation, monitoring of adverse effects of the Project pursuant to the Lake Winnipeg, Churchill and Nelson Rivers Study Board recommendations shall be planned and implemented so as to provide such information as may be necessary to give effect to this Agreement," and Article 18.2 which states: "Canada and Manitoba recognize that the Project is intended to benefit all citizens of Canada, and most particularly of Manitoba, on the one hand, and that the resource users have been and may continue to be adversely affected on the other hand, and that it is in the public interest to ensure that any damage to the interests, opportunities, lifestyles and assets of those adversely affected be compensated appropriately and justly."

Article 24 of the NFA establishes an arbitration process, by which "...any claim or matter in dispute submitted by any person..." can be heard by an arbitrator. In December 1981, the NFC filed Claim 18 which alleged that Canada, Manitoba, and Manitoba Hydro had failed to meet certain contractual obligations of the NFA, including a failure to implement a "...long-term coordinated ecological monitoring and research program (that) would allow evaluation of impacts on the bands and their members and communities..." and that "...this failure has resulted in the fact that the NFC and the bands and their members have suffered severe loss and damage." This claim was the impetus for FEMP.

FEMP, therefore, was a partial fulfillment of Canada's obligations under a legal contract, a sharp contrast to most government environmental programs that are implemented as a result of legislation or government policy. The NFA is, however, a difficult agreement to interpret and implement due to its complexity, breadth of scope, and the imprecision of many of its clauses (e.g. "eradicate mass unemployment and poverty"). The recent demise of a senior 4-party process, commonly referred to as global negotiations, intended to resolve outstanding commitments of the NFA illustrates this difficulty.

PROGRAM ADVISORY BOARD

As noted previously, Rec. #10 of the LWCN Study recommended the implementation of a long-term coordinated ecological monitoring and research program. However, until 1985, the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion was the only fully coordinated monitoring and research program to be implemented. Other environmental programs conducted in the LWCN impact area were single discipline and/or single agency programs.

In July 1985, Manitoba and Manitoba Hydro set up a two-party Program Advisory Board (PAB), to manage their biophysical monitoring programs. In September 1986, following the initiation of FEMP, the two-party PAB was expanded to a 4-party board, with members from Canada and the NFC, to facilitate the coordination of all programs. The 4-party PAB was a self-created coordinating mechanism; it had no official status to manage FEMP.

At the time, PAB was unique in that it was the only established mechanism for 4-party dialogue on any of the NFA provisions. Its creation offered the promise of a coordinated (and, ideally, a fully integrated) comprehensive ecological monitoring and research program. The 4-party PAB provided an opportunity whereby the direction and progress of FEMP, and its equivalent provincial and Manitoba Hydro programs, could be reviewed within the context of: (1) its success in addressing those environmental concerns of greatest interest to the NFA communities, as expressed by the NFC; (2) its contribution to an improved understanding of the environmental impacts of the LWCN project; and (3) its scientific merits.

The face-to-face contact which PAB provided in its more than 30 meetings facilitated: (1) spirited discussions of environmental issues; (2) information dissemination (e.g. production of a sediment atlas, FEMP Report #89-3); (3) field coordination (e.g. shared collection of water quality samples); and (4) data comparisons (e.g. an interagency comparison of field and laboratory procedures for the collection of suspended sediment data, FEMP Report #89-4). Unfortunately, however, the promise of the 4-party PAB was only partially realized; with only limited cooperative, and no truly integrated activities undertaken, the PAB process could be more appropriately described as an exercise in joint unilateralism. The lack of a formal structure, a common budget, and a shared vision on how best to realize PAB's objectives prevented the full attainment of its original purpose. Shortly after the commencement of the global negotiations process, PAB disbanded.

FEMP - AN ENVIRONMENTAL IMPACT ASSESSMENT?

An environmental impact assessment (EIA) is a systematic method of identifying potential environmental consequences and their impact on people, their livelihood and way of life. Ideally, an EIA should be conducted at a stage early enough to have an influence on the project development, before actions are taken that will result in an irreversible commitment of resources. In fact, a significant environmental impact has been defined as one which should be considered in project decisions (Beanlands and Duinker, 1983).

Traditionally, an EIA compares measured pre-project environmental conditions (or at least conditions that existed during the construction period) with anticipated post-project conditions. With the commencement of FEMP approximately 10 years after construction of the major hydro projects, it was the post-project conditions that were measured and, because of limited pre-project data, the pre-project conditions were often estimated. Hence, FEMP was not a traditional EIA.

FEMP was, however, guided by the principles of an ideal EIA, one that is developed and implemented within an ecological framework. These principles include: (1) the determination of a program focus, a process commonly referred to as scoping; (2) the recognition of the important interrelationship between socio-economic effects and environmental impacts; (3) the need for a sound scientific foundation for EIAs; and (4) the development of a program strategy and explicit objectives. Post-project monitoring, the major FEMP activity, is increasingly becoming an integral part of EIAs (Sadler 1986). For example, in Canada, Bill C-13, first introduced in June 1990, strives to improve the current environmental assessment process by requiring, for the first time, follow-up and monitoring plans for major projects. Thus, while not a true EIA, FEMP embodied many EIA attributes.

SCOPING

The NFA and Claim 18 firmly established that the purpose of the proposed ecological monitoring and research program had to be the evaluation of the impacts of the LWCN Hydroelectric Project on the bands and their members, but these documents did not provide any guidance on the direction or focus for this program, nor was such guidance provided in the policy statements or other correspondence prepared by the NFC. This material tended to concentrate on legislative requirements and conceptual frameworks (e.g. mandates, processes, etc.), rather than on program specifics (e.g. study priorities). For example, the NFC emphasized the need for "joint, collaborative and coordinated action," (March 9, 1986 letter to Manitoba Hydro), for "professionally developed scientific and environmental data," (May 20, 1986 letter to Manitoba Hydro), and for "full disclosure of all adverse effects of the project and their likely cumulative impacts over time," (NFC Guiding Principles - Discussion Phase I).

To address federal responsibilities under the NFA, FEMP clearly had to assume a community focus. Consequently, FEMP projects were limited to investigations of only those environmental conditions that were perceived to have had a direct impact on the bands and their members. For example, FEMP did not investigate the environmental impacts of the LWCN Hydroelectric Project on Hudson Bay; nor did it investigate the contribution of the extensive terrestrial flooding, caused by the hydro projects, to the production of greenhouse gases.

The scope of FEMP was further defined by examining relevant socioeconomic and scientific factors, as discussed in the next two sections. Pragmatic considerations were also important, such as : (1) the federal government's role in environmental monitoring and research; (2) the desire to avoid duplication of studies being conducted by the province and Manitoba Hydro; and (3) the limitations imposed by budgetary and temporal constraints.

Scoping is widely recognized as essential in environmental impact assessments, since no monitoring program, no matter how vigorously conducted can examine, let alone predict, all the effects of large-scale developments (Sadler 1986). Scoping was equally important to FEMP, since it could not have effectively monitored all of the post-project impacts of the hydro projects in northern Manitoba. However, scoping, by narrowing the focus of environmental studies, limits the depth and breadth of our understanding of the natural system and of changes to it; this contributes to the uncertainty of our predictive abilities with respect to the expected future regime and with respect to the impacts of changes in the environment on its dependent socioeconomic systems.

SOCIOECONOMIC CONSIDERATIONS

The relationship between social values and the scientific focus of environmental assessment studies is generally recognized and accepted in Canada. The "problems to be overcome seem less related to the importance of social values than their early identification and translation into appropriate environmental studies" (Beanlands and Duinker 1983, p. 3). This process involves two distinct but closely related components: (1) evidence of causality between observed ecological conditions and the project; and (2) an understanding of the social values of the people affected by the project.

By definition, evidence of causality is required to classify an observed ecological condition as a project impact. However, our knowledge of species ecology (Rosenberg et al. 1987, Suzuki 1988) and of the effects of reservoir changes on the higher tropic levels, like fish, (Hecky et al. 1984) is inadequate for a comprehensive assessment of impacts in a complex and severely altered environment, such as the aquatic environment in the FEMP study area. Indeed, we are still in the process of establishing these linkages. An excellent example of this was the determination of the process by which methyl mercury levels increased in fish following extensive flooding.

Characterization of an ecological condition as a significant effect of the project depends upon the magnitude of the impact, its severity, spatial and temporal characteristics. Further, characterization of a project effect as adverse, beneficial or neutral introduces a valuation concept, usually an economic valuation, which is "primarily anthropocentric and ethnocentric so that it is the value of the affected resource to man in a particular social context and not to the ecosystem as a whole which is determinative" (CEARC 1988, p. 3). The social context in which this valuation occurs in Canada is that of the dominant social group, a European-descendent, urban population living in southern Canada. However, the value of water in its natural state to this dominant social group differs from that of native groups, for whom water issues transcend strictly economic, environmental or recreational concerns; they are a matter of identity (Barton 1987). This difference in valuation of water is further compounded by differences in cultural expression, differences which have not been recognized in the implementation of government programs in the communities in the FEMP study area (McKerness 1989 a).

When FEMP began in 1986, there was insufficient information about the relevant social values of the communities in the FEMP study area to enable their "translation into appropriate environmental studies." Nor was it possible to "translate" the results of past environmental studies into a full understanding of their implications on the socioeconomic well-being of the residents of these communities. For example, lack of information on domestic fish consumption patterns in the communities prevented a full understanding of the socioeconomic effect of elevated mercury levels in fish following flooding.

PAB members recognized the inadequacies of the existing socioeconomic information and individually and collectively tried to address this need. For example, in 1986 the NFC identified four research tasks for socioeconomic assessment and monitoring: (1) a literature search; (2) an audit of results from other similar cases; (3) scoping requirements; and (4) community participation. Subsequent discussions eventually led to the formation of a socioeconomic sub-committee of PAB to examine possible terms of reference for an NFA-specific social impact assessment and monitoring strategy, and to discussions with the Canadian Environmental Assessment Research Council regarding their possible contribution to this process. Unfortunately, this initiative was not pursued.

In 1988, DFO hosted a workshop to "determine the feasibility of doing a retrospective analyses of the biophysical social and economic impacts of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project on the commercial and domestic fishing practices of the five communities signatory to the Northern Flood Agreement". One of the products of this workshop was DFO's sponsoring of a study to examine resource harvesting data to assess their suitability for use in a social impact assessment. The other product was a study to synthesize the available information on the physical, chemical and biological impacts of the hydro projects on the aquatic ecosystems in the FEMP study area.

DFO worked closely with the NFC in developing the terms of reference for both studies. NFC involvement was recognized as critical to the identification of the specific project-related socioeconomic concerns of the community residents and in facilitating direct community participation in these studies. The results of these studies, which are presented in Volume 2 of this report, were only available near the end of FEMP and were therefore of only limited value in developing the focus for FEMP. However, the open and continual dialogue with the NFC during the planning of these studies increased the sensitivity of FEMP to community needs.

The difficulty experienced in incorporating socioeconomic considerations into FEMP, and at a stage early enough to influence FEMP's direction, is an example of the well-known and documented difficulty in conducting social impact assessments (SIA) and cumulative effects assessments (CEA). Reasons for this difficulty include: (1) an inherent situation of complex causality, where the impact is a joint effect of characteristics of the perturbation and the existing systems and conditions; (2) high uncertainty about social values; (3) the need for an improved understanding of ecological science; and (4) the lack of suitable assessment methods, including the integration of possible linkages (Sonntag et al. 1987, SCC 1988).

SCIENTIFIC PROCEDURES

All environmental studies have to be based on sound scientific procedures; otherwise, such studies run the risk of "degenerating into an exercise in public relations and government lobbying" (Beanlands and Duinker 1983, p.21). The need for sound scientific procedures was especially critical to FEMP to ensure an objective investigation in a situation complicated by an often adversarial political and legal climate.

Scientific principles which guided FEMP included: (1) the establishment of objectives which were scientifically realistic; (2) the explicit statement of all assumptions; and (3) good research design, including testable hypotheses and appropriate statistical treatment of data. An especially important decision was the selection of the appropriate level of scientific standards.

The scientific rigour with which environmental studies should be conducted has been the object of some discussion (e.g. Rosenberg et al. 1981, Couch et al. 1981). Scientific standards can vary from the extreme rigour required for advanced scientific research to the other extreme where the "science" involved is reduced to a gathering of "experts" to produce their best guesstimates (Beanlands and Duinker 1983). Given that the impetus for FEMP was the NFA, and not the pursuit of scientific research, and that NFA Article #23.2 places the onus on Manitoba Hydro to establish that its development did not cause nor contribute to an adverse effect, it can be argued that extreme scientific rigor was inappropriate for FEMP. However, the other extreme of providing guesstimates, was equally inappropriate.

The magnitude of the environmental changes that have occurred as a result of the hydro project and the importance of this environment in the daily lives of the approximately 14 000 local inhabitants warranted the use of the best tools available to improve our understanding of these changes. It was important to understand not only those changes that had already occurred, but also those that are expected to occur as the system restabilizes from the impact of past hydro dams and dams scheduled for construction. A secondary use of this improved understanding is to add to the general knowledge of post-development environmental conditions, a subject that has often been characterized on the basis of unverified predictions (Beanlands and Duinker 1983).

Thus, it was decided that FEMP must be implemented with a strong emphasis on scientific rigour. This process included: (1) selection of well-qualified project leaders; (2) review of proposed FEMP projects, in part to ensure that specific project objectives were in accordance with FEMP objectives; (3) compilation and review of all existing relevant scientific information, including some data collected through concurrent non-FEMP programs (e.g. preparation of an annotated bibliography, FEMP Report #87-1; compilation of a water quality data base; etc.); (4) technical review of project findings; and (5) annual examinations of FEMP's progress and of its future direction. The selection of scientific methodologies, the critical step in this process, is discussed in chapter 4 of this volume.

STRATEGY

The factors discussed in this chapter, and those discussed in more detail in chapters 4 and 5, formed the basis for the FEMP strategy. In particular, 5 principles were formulated to guide FEMP, as follows: 1) FEMP must address federal obligations under the NFA, with respect to environmental monitoring; 2) FEMP projects must be designed and implemented on the basis of sound scientific procedures; 3) input into the planning and implementation of FEMP must be actively solicited from PAB and, to assist them in this task, interim findings must be provided to them; 4) the environmental and related socioeconomic concerns of the community residents, as expressed by the NFC, must be important considerations in the planning and implementation of FEMP; and 5) FEMP findings must be presented in formats that are appropriate for the intended audiences, especially the native communities in the FEMP study area.

FEMP OBJECTIVES

The objectives of PAB, namely: 1) "to determine project-induced ecological and socioeconomic changes, impacts and adverse effects within the affected resource areas of the NFA communities"; and 2) "to provide an information base to assist in the design and implementation of appropriate compensation, mitigation and/or remedial works and measures for adverse effects," guided the formulation of FEMP objectives, which were as follows: 1) to the extent possible, determine pre-project conditions (e.g. by examining historical data and interpretative reports on the ecological conditions in the FEMP study area, and by using remote sensing techniques); 2) to monitor post-project conditions; 3) to increase our understanding of the significant factors that could affect future ecological conditions in the FEMP study area, such as the recovery time of present impacts (e.g. mercury) and the determination of potential impacts from future planned developments; and 4) to advise the public of FEMP results, ensuring that this information is presented in formats appropriate to the intended audiences, and most especially to the native communities in the FEMP study area.

Together, FEMP objectives #1 and 2 addressed, at least partly, PAB objective #1 by assessing changes in the ecological conditions since the LWCN project. FEMP objective #3 was a response to PAB objective #2, in recognition that the long-term effectiveness and cost of compensation, mitigation and remedial measures will be affected by future ecological conditions and therefore such conditions must be estimated to ensure the selection of the most appropriate measures. FEMP objective #4, by ensuring that the salient FEMP findings are presented in a comprehensible manner, was essential to the fulfilment of both PAB objectives.

DEPARTMENTAL ROLES

FEMP was a cooperative program of Environment Canada (DOE) and Fisheries and Oceans Canada (DFO) and consequently, it reflected the departmental mandates, expertise, and historical involvement in the FEMP study area of these two departments. DOE's focus was on the water resources and migratory birds, with the geographical areas of focus being the immediate vicinities of the native communities in the FEMP study area. DFO's focus was on fisheries and fish habitat and, as a result, their geographical areas of focus were primarily Southern Indian Lake and Playgreen Lake, lakes which support major fisheries in the FEMP study area.

DOE and DFO also differed in the approaches they took to solicit community input into their programs. DFO sought NFC advice on their planned FEMP activities. For example, DFO did not pursue their intention to conduct an intensive investigation of Playgreen Lake, similar to DFO's case study of Southern Indian Lake, because of lack of NFC support. Instead, DFO conducted only a limited study of Playgreen Lake and sponsored two studies that, at least partly, addressed NFC's concerns about socioeconomic adverse effects. DOE also maintained regular dialogue with the NFC, especially via the PAB meetings, but it also tried to obtain direct community participation in some of its FEMP projects. For example, as part of the FEMP waterfowl projects, hunters from Norway House and Nelson House were interviewed and some of these individuals were taken on the aerial surveys.

The distinguishing characteristic, however, of the DOE and DFO roles in FEMP was the strong collaboration between the departments. Numerous tasks were jointly planned, undertaken and/or cost-shared, such as: (1) mapping the FEMP study area; (2) assessing the quality of various data bases (e.g. sediment data); (3) conducting mercury studies; and (4) preparing FEMP reports. This close and effective working relationship, which was developed during their participation in the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion, was further enhanced by the shared commitment of these same individuals to FEMP.

Figure 3.1 Chronology of Key Events

early 1900s -	federal water power surveys identify hydroelectric potential of Churchill River.
1940s -	extensive provincial surveys beginning in the 1940s confirm this potential, and hydroelectric feasibility studies commence.
mid 1950s -	discovery of possibility for diversion of the Churchill River flow into the Nelson River basin.
1960s -	feasibility studies by Manitoba Hydro indicate that a high-level impoundment of SIL and diversion of Churchill River water into the Nelson River would optimize electric generation benefits relative to all other possible system configurations.
1961 -	construction of the first power station on the Nelson River, the Kelsey Generating Station.
1970 -	first published predevelopment impact assessment, a response to strong public resistance to the high-level impoundment scheme; subsequently Manitoba Hydro opted for a low level impoundment.
1975 -	completion of a federal-provincial study which studied the environmental effects of the LWCN hydro project.
1976 -	completion of control structures at Southern Indian Lake and Notigi, and of the excavated diversion channel from Southern Indian Lake.
1977 -	completion of construction works at outlet of Lake Winnipeg and the commissioning of the Jenpeg Control Structure and Generating Station.
1978 -	ratification of the Northern Flood Agreement, an agreement intended to ensure that all persons represented by the NFC who are adversely affected by the LWCN project receive fair and equitable treatment.
1981 -	the NFC filed Claim 18, under the NFA, alleging that the other 3 NFA parties had failed to meet certain contractual obligations of the NFA, including a failure to implement a long term coordinated ecological monitoring and research program.
1983 -	the signing of the first (and to date only) federal-provincial post-development agreement to study an environmental impact of the LWCN project, mercury in the Churchill River Diversion area.
1985 -	the province of Manitoba and Manitoba Hydro set up a two-party Program Advisory Board (PAB) to manage a biophysical monitoring program within areas of provincial interest.
1986 -	Environment Canada and the Department of Fisheries and Oceans began their biophysical monitoring program; PAB was expanded to include representatives from the federal government and the NFC.
1988 - 1990	discussions took place under the auspices of a senior level, 4-party committee to resolve outstanding issues of the NFA.

CHAPTER 4

FEMP SCIENCE

INTRODUCTION

Scientific rigour was emphasized throughout FEMP to ensure that information was obtained and analyzed in an objective, accurate, and logical manner. A wide variety of scientific methodologies were employed, reflecting the diversity of scientific disciplines encompassed by FEMP and the continuing advances being made in our ability to measure environmental parameters. Some of these methodologies are highlighted in this chapter. The chapter concludes with an example of the need to understand the cause of observed changes in the environmental parameters and in particular the importance of discriminating between natural and anthropogenic effects.

SATELLITE REMOTE SENSING

Satellite remote sensing is one of two principal visual remote sensing techniques, the other being aerial photography, in which information about an object, area, or phenomenon is obtained through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation. Historically, remote sensing consisted of aerial photography from various airborne platforms. With the advent of space flight and improvements in computer technology, satellites began collecting digital imagery of the earth's atmosphere and surface.

Beginning in July 1972, a series of five Landsat satellites were launched, of which the last two are still operational. These satellites provide two different types of remote sensing images: Multispectral Scanner images (MSS) and Thematic Mapping (TM) images. Higher spatial and spectral resolution is provided by TM images, however these images are more expensive to purchase than MSS images and have only been available since 1982.

To assist researchers in determining the amount of useful satellite imagery in the FEMP study area, a remote sensing catalogue of the area was produced (FEMP Report #87-3). This catalogue consists of: 1) a user guide; 2) a complete listing of all available remote sensing; and 3) guidance on the quality of the MSS images [e.g. maps that show the cloud-free area (less than 50% cloud cover) on all images].

The Landsat MSS system records four segments, or bands, of the spectrum of reflected light, two that are different wavelengths of infra-red light and two that correspond approximately to blue-green and orange-red light. Infra-red light is strongly reflected from most of the terrestrial surface of the earth, but is mostly absorbed by water; hence, it is very powerful in discriminating land from water in satellite images. Visible light is also generally absorbed by water; however, suspended material in water tends to reflect light in proportion to its concentration. Thus, the visible light record on Landsat MSS images can be used to estimate suspended sediment concentrations in large lakes and impoundments. Both applications were used in the FEMP study.

The ability to distinguish land from water in satellite images was graphically illustrated in the colour enhanced Landsat images shown in chapter 2. It was also invaluable in determining the changes in surface areas of the FEMP lakes that were recorded in Fig. 2.7.

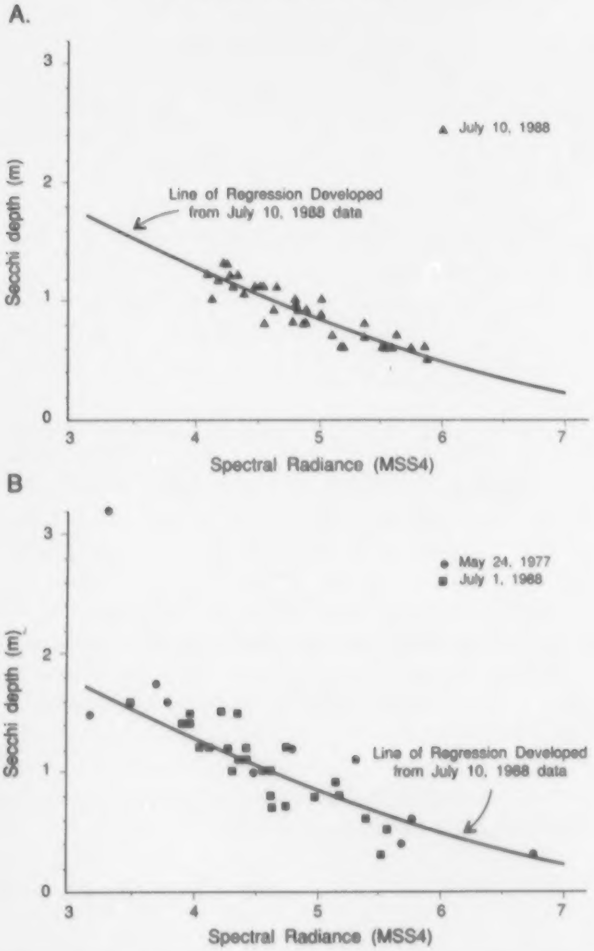
The principle that water absorbs visible light in proportion to its suspended sediment concentration was used to develop a model to determine suspended sediment concentrations in the FEMP study area. There has been only intermittent records of suspended sediment concentrations in the FEMP area; the large size and isolation of this area have precluded extensive on-lake monitoring programs. Suspended sediment data are particularly limited for the pre-development period. Successful development of a Landsat-based suspended sediment model would enable increased spatial and temporal coverage.

A series of physical measurements were taken at sites throughout Southern Indian Lake (SIL), coincident with the satellite overpasses of July 1, 1988 and July 10, 1988. Secchi disc measurements, as well as suspended sediment concentrations, were taken since there is a long record of such measurements at SIL and previous research has shown a relationship between Secchi disc measurements and suspended sediment concentrations. A satellite image from May 24, 1977 was also obtained, along with Secchi disc values that had been measured on May 23 and May 25, 1977. All sample site locations were identified relative to distinctive land features (e.g. bays) and marked on National Topographic Service map sheets for comparison to the satellite images.

Information from the Landsat satellite images was corrected to adjust for known potential sources of differences between images, such as differences in atmospheric contributions of light (e.g. smoke). Corrected values from the images were then compared to different forms of the Secchi disc data (e.g. log of Secchi disc data) to determine the best relationship, as determined by statistical analysis (Fig. 4.1.a). A comparison of the model developed from the July 10, 1988 data with the observed values from July 1, 1988 and May 24, 1977 is shown in Fig. 4.1.b.

Clearly, the model shows promise as a means of estimating Secchi disc measurements from Landsat images, and consequently, of suspended sediment concentrations. However, additional research must be conducted to fully verify this model, both temporally and spatially. A major temporal consideration is the fact that the spread of Secchi disc data was much greater historically (e.g. in 1977, the range was 0.2 to 4.2 m), a time when SIL was generally less turbid, than it is now (e.g. in 1988, the range was only 0.5 to 1.3 m). In this regard, historical Landsat MSS images and Secchi disc data available for SIL will be used to improve the model. Similarly, the spatial universality of the model must be tested. For example, one method to test the model across space is to apply it to Split Lake, a lake for which there is a set of 5 ground samples, associated with a Landsat image. If verified by further testing, the Landsat-MSS Secchi disc data model could provide a valuable tool for assessing suspended sediment concentrations, since 1972, over the entire FEMP study area.

Figure 4.1 Relationship between Observed Secchi Disc Values and Spectral Radiance in Landsat MSS Band 4, for Southern Indian Lake

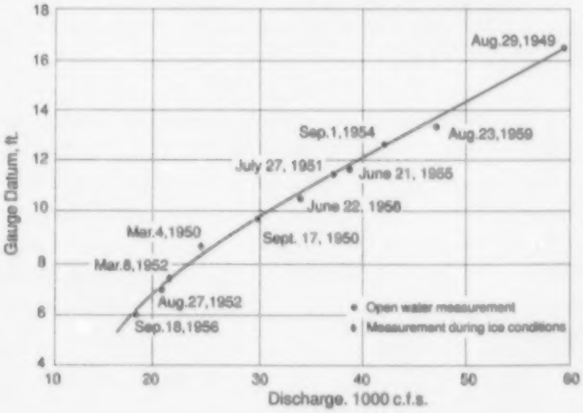


MEASURING DISCHARGE FROM SOUTHERN INDIAN LAKE

Streamflow data are usually derived from continuous or frequent (daily) records of water level or stage and periodic measurements of discharge. Derivation of streamflow data in this manner is made possible because, for most streams, there is a unique relationship between the water level of the stream at a particular location and the flow of the stream passing that location. This relationship is known as a stage - discharge curve. An example of such a curve is shown in Fig. 4.2.

For most stream stations, a simple rating curve is adequate. Periodic discharge measurements are made to determine whether or not the relationship is changing. Changes may occur at varying intervals depending on the characteristics of the stream bed, the velocity of the stream,

Figure 4.2 Stage - Discharge Curve for Churchill River above Granville Falls



the composition of the banks, and the severity of ice conditions. If the relationship changes, sufficient discharge measurements must again be made to define the new relationship.

At the South Bay diversion channel, which was constructed to divert the Churchill River at Southern Indian Lake, a unique relationship between water level and discharge does not exist. As a consequence, derivation of discharge using the traditional means of a stage - discharge curve was not possible here. Until recently, discharge at this site had to be estimated on the basis of measurements taken at the Notigi Control Structure.

In the late 1980s, direct measurement of the discharge from the South Bay diversion channel became possible with the installation of an Acoustic Flow for Remote Areas (AFFRA) Unit, purchased through FEMP. AFFRA, the product of recent, affordable technological advances, uses ultrasonic principles to measure water velocities, water depths, and velocity of sound in water. An example of water velocities and stage recorded by the AFFRA unit at South Bay is shown in Fig. 4.3. The water velocities are multiplied by cross-sectional area to provide water discharge and the velocity of sound in water is used to compute water temperature.

The same electronic circuitry used to transmit, receive and time velocity pulses is also used to measure depth of water above vertically mounted transducers. Traditionally, water level measurements, whether they are made downward from above the water surface or upward from below the water surface, have been prone to inaccuracies primarily due to changes in the temperature of the pulse transmitting medium, i.e. air or water, which changes the velocity of sound. With AFFRA, this is not a problem. The velocity of sound in water is a continuously measured by-product of the water velocity measurement.

The uniqueness of AFFRA in comparison to all other flow measuring systems, in its price range, is that it can provide velocity and stage data at a site on a continuous basis. This provides the means to compute discharge under any type of existing flow conditions. The fact that stage is measured from the bottom up permits the measurement of the "effective stage" under ice conditions, i.e. the stage associated with the area of flow. All other conventional stage sensors are pressure sensors under solid ice cover conditions. Hence, they measure the sum total of water, ice and any accumulation of snow, water or debris on the surface of the ice. This property of total pressure sensing, makes conventionally sensed stage virtually useless in determining discharge under variable backwater conditions due to ice effects. The AFFRA unit, however, provides accurate measurements under both open water and ice covered conditions.

Persistent difficulties in the satellite transmission of the data generated by the South Bay AFFRA unit, which were experienced in the start-up period, have now been overcome. Data from this site will be incorporated into the hydrologic monitoring network for the FEMP study area.

MEASURING SEDIMENT DEPOSITION

Impoundment of Southern Indian Lake by 3 metres raised the focus of wave energy above a generally stable shoreline of water-washed bedrock and long, sand and pebble beaches into glacio-lacustrine silts and clays. Three to four million tonnes per year were added to the lake by erosion in the early years after impoundment, about 15 times the natural riverine load. While sediment discharged from the lake has increased four times, most of the new load has been deposited either as near shore deposits up to 1 metre thick, or in deep water where 5 to 10 centimetres (cm) of post-impoundment sediments have been measured.

One method used to measure sediment deposition is the analysis of core samples extracted from the lake bottom. For example, new data on post-impoundment sedimentation rates have been based on a preliminary set of samples taken in 1987 as part of the FEMP sediment studies, in selected areas of Southern Indian Lake (SIL) and analyzed at 2 cm intervals for radioactive lead (^{210}Pb) and radioactive cesium (^{137}Cs) content.

Most ^{137}Cs in sediments is a product of deposition related to atmospheric testing of nuclear weapons. The rate of atmospheric ^{137}Cs fallout peaked in 1963; hence ^{137}Cs peaks in lacustrine sediments, such as those found in SIL, are considered to mark sediments deposited in the period 1962 to 1965. In SIL cores, this marker should be in sediments just below the pre-impoundment/post-impoundment interface. As shown in Fig. 4.4, ^{137}Cs does show a sharp peak in most cores, at depths ranging from 5 to 11 cm.

Figure 4.3 *Measurements of Velocity and Stage at Southern Indian Lake Diversion Channel, by the AFFRA Unit*

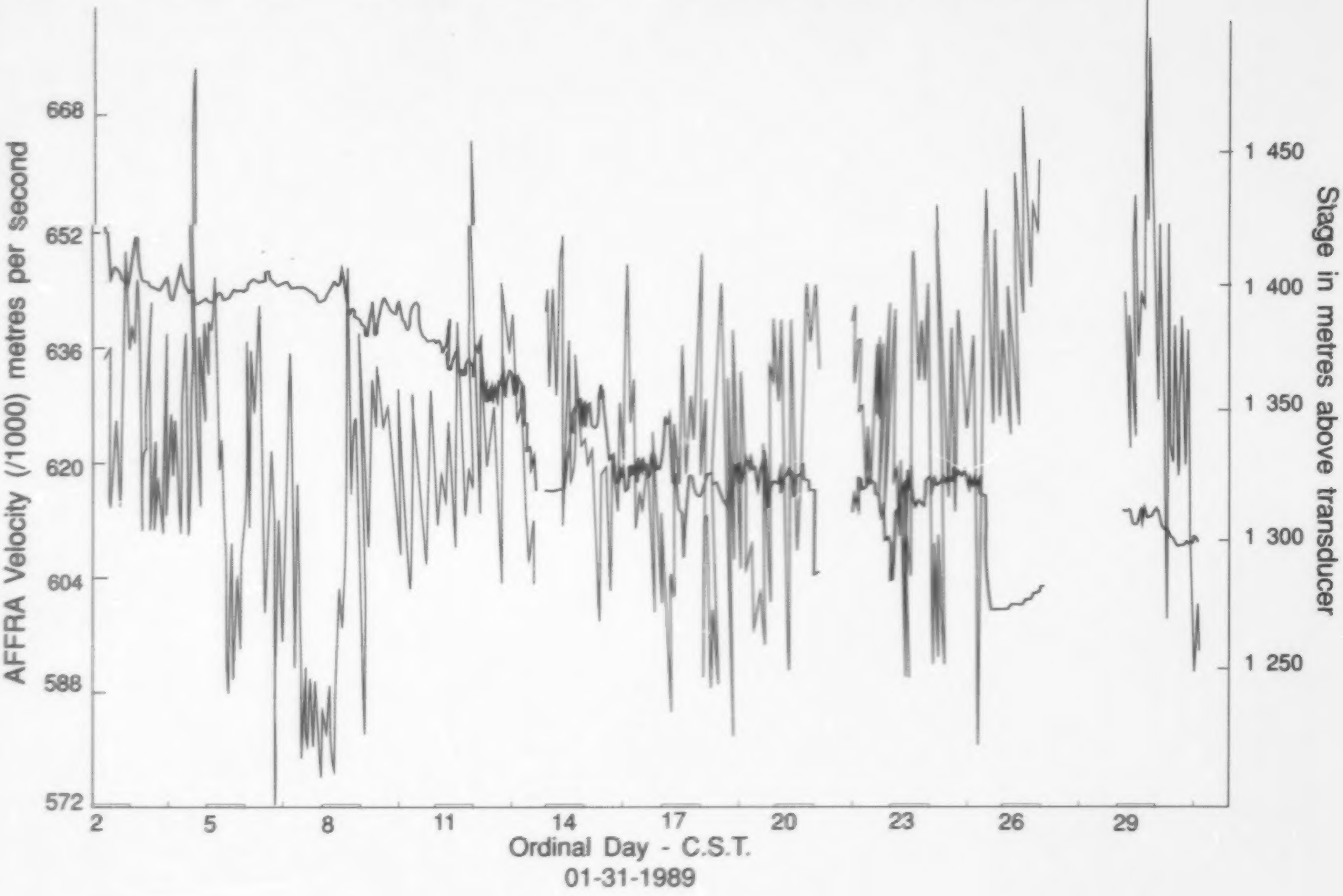
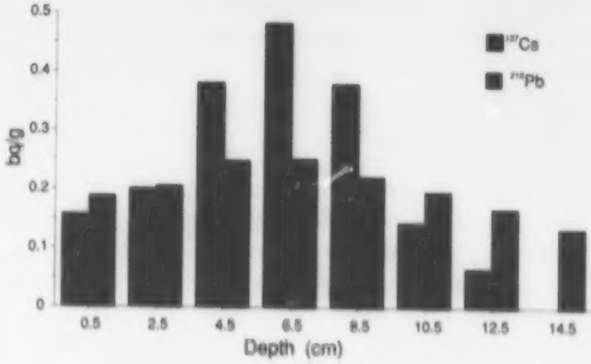


Figure 4.4 ^{210}Pb and ^{137}Cs Content in Sediments Plotted against Depth below the Sediment/Water Interface, Southern Indian Lake



^{210}Pb is a natural product of radioactive decay of uranium and, for given regions, is deposited at a fairly constant rate from the atmosphere into lakes, and then into lake sediments. Although ^{210}Pb production by radioactive decay also occurs within sediments, the rate of ^{210}Pb deposition from the lake waters into the sediment is generally well in excess of this internal ^{210}Pb production. Hence, because ^{210}Pb decays with a half life of 22.2 years, where the total sediment deposition rate is constant in the long term, the concentration of ^{210}Pb in the sediments decreases in a predictable way from the sediment/water interface downward into the sediments. (For example 44 year old sediments should contain only half as much excess ^{210}Pb as the 22 year old sediments above, and so on down.) Such a constant decay curve does appear to be found in SIL sediments below 5 to 11 cm depth. There is generally a prominent break in the curve in this depth range which coincides with the ^{137}Cs peak. (See Fig. 4.4.) ^{210}Pb levels in sediments above this break are lower and may be indicative of a higher total sedimentation rate relative to ^{210}Pb deposition; in any case, the break in the decay curve is interpreted as marking a sharp change in sedimentation rate. The coincidence of the peak in ^{137}Cs concentration curve with the break in the ^{210}Pb curve are strongly supportive evidence that the latter is a marker for the pre-impoundment/post-impoundment sediment interface in SIL.

MEASURING MERCURY LEVELS IN WATER

Mercury in the FEMP study area has been an important issue since the discovery, in the late 1970s, of elevated mercury levels in fish from the lakes along the Churchill River Diversion route. In the early to mid 1980s, federal and provincial scientists investigated this issue under the auspices of the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA). The major conclusion of the CMMA study was that increases in the net rate of methyl mercury production, which occurred in areas of flooded terrain, had resulted in elevated mercury levels in fish. It was also concluded that there was no evidence that flooding had caused an increase in mercury concentration in water of any of the reservoirs studied.

When the CMMA studies were conducted, the best analytical methods then available were not sensitive enough to detect very low levels of mercury in water. A surrogate method, that of measuring mercury concentrations in plankton, was used to provide a relative measure of mercury concentrations in water. Through this method, it was found that mercury levels in the flooded reservoirs and control lakes in the CMMA study area were similar, and both were comparable to mercury levels reported for other uncontaminated water bodies elsewhere in the world.

Since the completion of the CMMA study there have been improvements in the analytical methods to detect mercury in water. In 1986, direct measurement of total mercury concentrations in water became possible, and in 1989, a highly sensitive method was developed to detect trace levels of methyl mercury in water, the form of mercury that accumulates in fish. Using these methods, measurements of total and methyl mercury in water were conducted, as part of the FEMP mercury studies, to address the concerns of the area's residents about mercury levels in their drinking water and to improve our understanding of mercury dynamics in the aquatic environment, such as mercury speciation and spatial distribution.

The direct measurements of total mercury concentrations in water conducted under FEMP confirmed the CMMA conclusion, based on mercury analysis of plankton, that total mercury concentrations were not higher in reservoirs than in a reference lake (Fig. 4.5). However, reservoirs did have higher concentrations of methyl

Figure 4.5 Mercury Concentrations in Water in Northern Manitoba Lakes and Reservoirs, 1989

		Total Hg ($ng \cdot L^{-1}$)		Methyl Hg ($ng \cdot L^{-1}$)	
Granville	- nearshore	1.44	(0.70-1.82)	0.021	(0.013-0.033)
	- offshore	1.50	(0.66-2.37)	0.023	(0.020-0.038)
Southern Indian					
Methyl Bay	- nearshore	1.18	(0.71-2.37)	0.034	(0.028-0.045)
	- offshore	1.60	(0.73-3.15)	0.017	(0.014-0.023)
Notigi West		1.07		0.046	
Burntwood River at Thompson		2.10		0.027	(0.023-0.031)
Stephens	- nearshore	1.77	(1.07-2.70)	0.037	(0.027-0.044)
	- offshore	1.28	(0.81-1.73)	0.054	(0.041-0.060)

mercury than the reference lake. In both the reservoirs and the reference lake, methyl mercury accounted for only a very small portion (approximately 1 - 5%) of the total mercury concentrations in water.

The range of methyl mercury concentrations in the Burntwood River at Thompson was not appreciably different from that at Granville Lake. This suggests that methyl mercury produced in the flooded reservoirs upstream does not travel as far as Thompson, 130 km downstream of the Notigi Control Structure. Additional measurements of methyl mercury in water, especially at sites located within 130 km of an upstream reservoir, would be needed to determine the actual limit of downstream transport of methyl mercury in the FEMP study area.

MEASURING BACTERIA LEVELS IN WATER

A limited bacteriological study of the recreational and potable waters in the 5 NFC communities was conducted, in 1987, as part of the FEMP's water quality studies. At this time, concerns were expressed by community residents about ongoing problems in the bacteriological program routinely conducted in their communities by Health and Welfare Canada (HWC), such as limited sampling frequency, lengthy delays in the receipt of results, and the lack of guidance on the meaning of the results. To alleviate these problems, a community-administered bacteriological assessment program was proposed; as a consequence, a FEMP pilot project was conducted in Split Lake, in 1988, in conjunction with HWC.

Four simple, inexpensive bacteriological tests were selected for assessment in the pilot project. A small basic laboratory was established in the basement of the Nursing Station at Split Lake and equipped with the necessary supplies to perform all four tests. Mr. V. Spence, a community health representative, was trained in the sampling and analysis procedures. Mr. Spence is a Split Lake resident who had no previous experience with the type of field and laboratory techniques used in this program. Tests were conducted of the bacteriological quality of drinking water from a number of locations (e.g. the water treatment plant and distribution system, water barrels in private residences) and of the recreational water at a number of beaches near the community.

The pilot project clearly demonstrated its value in providing timely analysis of the bacteriological quality of the community's drinking water and in identifying possible sources of contamination, enabling corrective measures to be taken. For example, samples taken from one of the two water delivery trucks showed frequent contamination; this knowledge increased awareness of the need for proper handling and cleaning of the water trucks. The pilot project also identified where improvements could be made in the methodology, such as greater quality control and the need for additional training.

The results of the pilot project were so promising that it attracted the interest and support of the International Development Research Centre (IDRC) in Ottawa. The IDRC's support and the increasing community commitment to this project has escalated community involvement to a three-man team of investigators, trained sufficiently to maintain and report on the bacteriological quality of the community's drinking and recreational waters. Furthermore, the IDRC is proposing to create a fund for the long-term support of this program and to consider the development of a separate laboratory facility which could be used for a number of environmental assessment options.

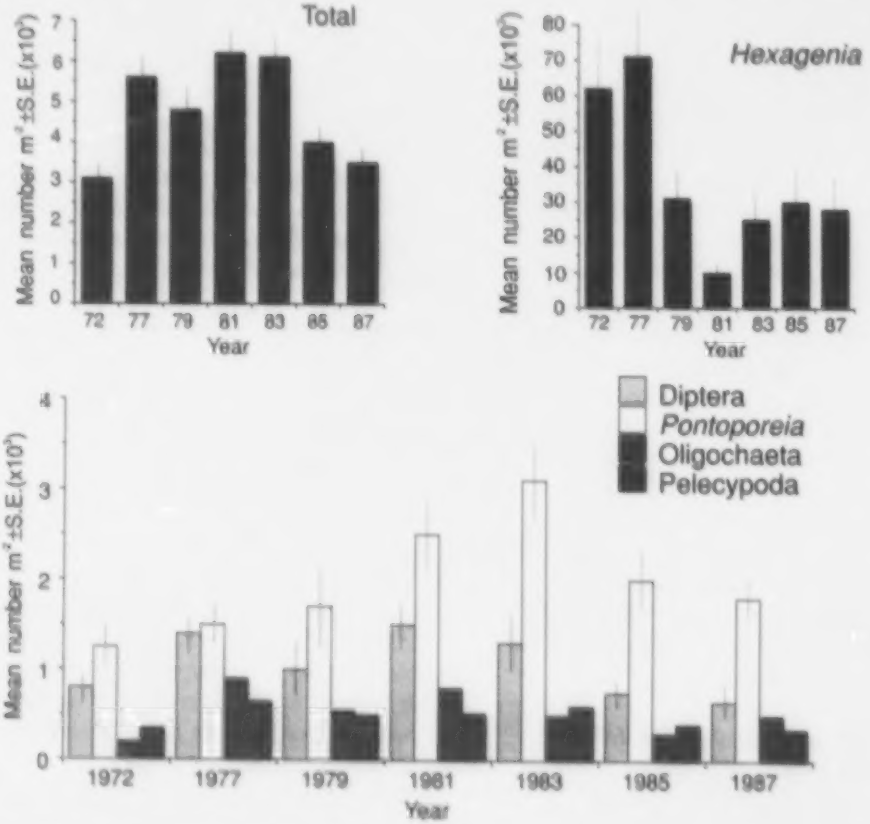
The community-administered bacteriological assessment program has given the community the training and experience with the scientific tools needed to develop an understanding of the bacteriological quality of their waters. The success of the program in Split Lake offers the exciting possibility that it can be implemented in other isolated communities in Canada and elsewhere in the world where the bacteriological quality of the water is a concern.

BURROWING MAYFLIES IN SOUTHERN INDIAN LAKE

New reservoirs typically experience a trophic upsurge, an increase in the aquatic biomass, immediately following impoundment. This results from an initial input of nutrients and organic matter originating from newly flooded land. The subsequent depletion of this material then results in a decrease in the aquatic biomass to near or below pre-impoundment levels.

In Southern Indian Lake (SIL), the only biotic group to show this pattern was the benthic macroinvertebrates. The four most abundant benthic groups, the immature flies (Diptera) the freshwater shrimp (Amphipoda; *Pontoporeia brevicornis* grp.) the aquatic worms (Oligochaeta), and the freshwater clams (Pelecypoda) all responded similarly, thus creating the overall pattern shown in Fig. 4.6. However, an opposite pattern was observed for burrowing mayflies (*Hexagenia limbata* and *H. rigida*). Lakewide standing stocks increased slightly following impoundment, but fell dramatically

Figure 4.6 Benthic Invertebrate Abundance in Southern Indian Lake, 1972 - 1987



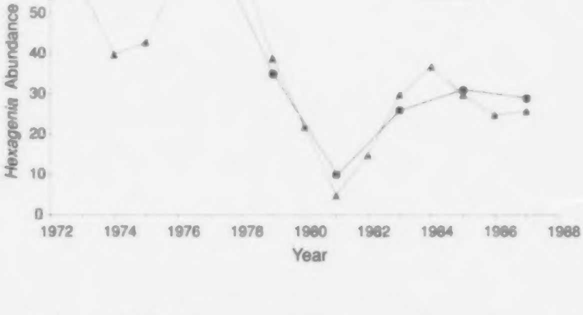
slightly following impoundment, but fell dramatically following diversion to approximately 15% of the predevelopment level by 1981.

Following the 1983 survey, the reduction in burrowing mayflies standing stocks was attributed to an inability by burrowing mayflies to maintain their burrows because of severe shoreline erosion and altered substrate composition, and to a decrease in water temperatures in the northern part of the lake because of river diversion and incipient thermal stratification. Had no further surveys been done the reduction in the burrowing mayflies would have been attributed, erroneously, to the manipulations of the lake for hydroelectric development. However, the surveys were continued, and although standing stocks never returned to the pre-development level during the 10 years of post-development monitoring, populations increased substantially after 1981 and stabilized at approximately 50% of the 1972 level, despite the fact that impoundment and diversion still affected the lake. In order to interpret the long-term survey data, a doctoral study of the life history of burrowing mayfly populations in SIL was initiated in 1986. (Giberson 1991)

Weather conditions affect the abundance of burrowing mayflies in three major ways in SIL: (1) cooler water temperatures extend duration of the nymphal life cycle, which results in a higher probability of natural mortality, fewer emerging adults, and lower reproduction; (2) water temperatures affect egg hatching success, i.e. fewer eggs hatch at lower temperatures; and (3) windy or stormy weather during emergence periods results in high mortality and low mating success, again limiting recruitment. One weather variable, air temperature (expressed as atmospheric degree-days (dd) greater than 0°C during the open-water season), correlates well with the factors that affect burrowing mayfly abundance in SIL. Most areas of the lake do not thermally stratify, so bottom water temperatures are directly related to air temperatures during the open-water season. Also, during the 10-year period of weather records for SIL, windy and stormy conditions during emergence were associated with cool mean summer air temperatures, whereas calm and clear summers were usually warm. Moreover, air temperatures greater than O°C are biologically important because they contribute to heating the water mass up to the 8°C developmental threshold for burrowing mayflies in SIL.

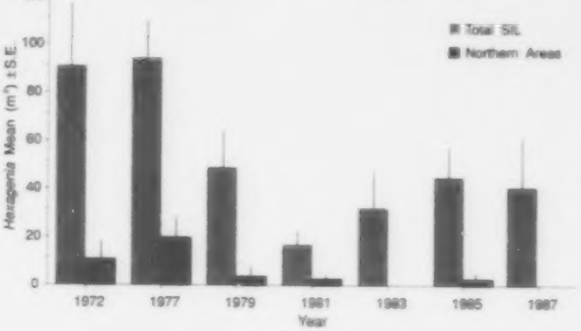
Thus, air temperatures were used in the following predictive manner; when atmospheric dd greater than O°C (from July - July) were averaged over 3 years, (the life cycle of the burrowing mayfly in most parts of SIL) regressed against their mean abundance in SIL (no.m^{-2}), more than 95% of the variability in burrowing mayfly standing stocks during the study period could be explained. The resulting relationship was then used to predict burrowing mayfly abundance based upon air temperatures alone (Fig. 4.7). The close relationship between predicted abundances and those observed in each lake survey indicates the importance of temperature in regulating populations of burrowing mayflies in SIL.

Figure 4.7 Relationship between Observed Abundances of Burrowing Mayflies and Predicted Abundances, Based on Air Temperatures, Southern Indian Lake

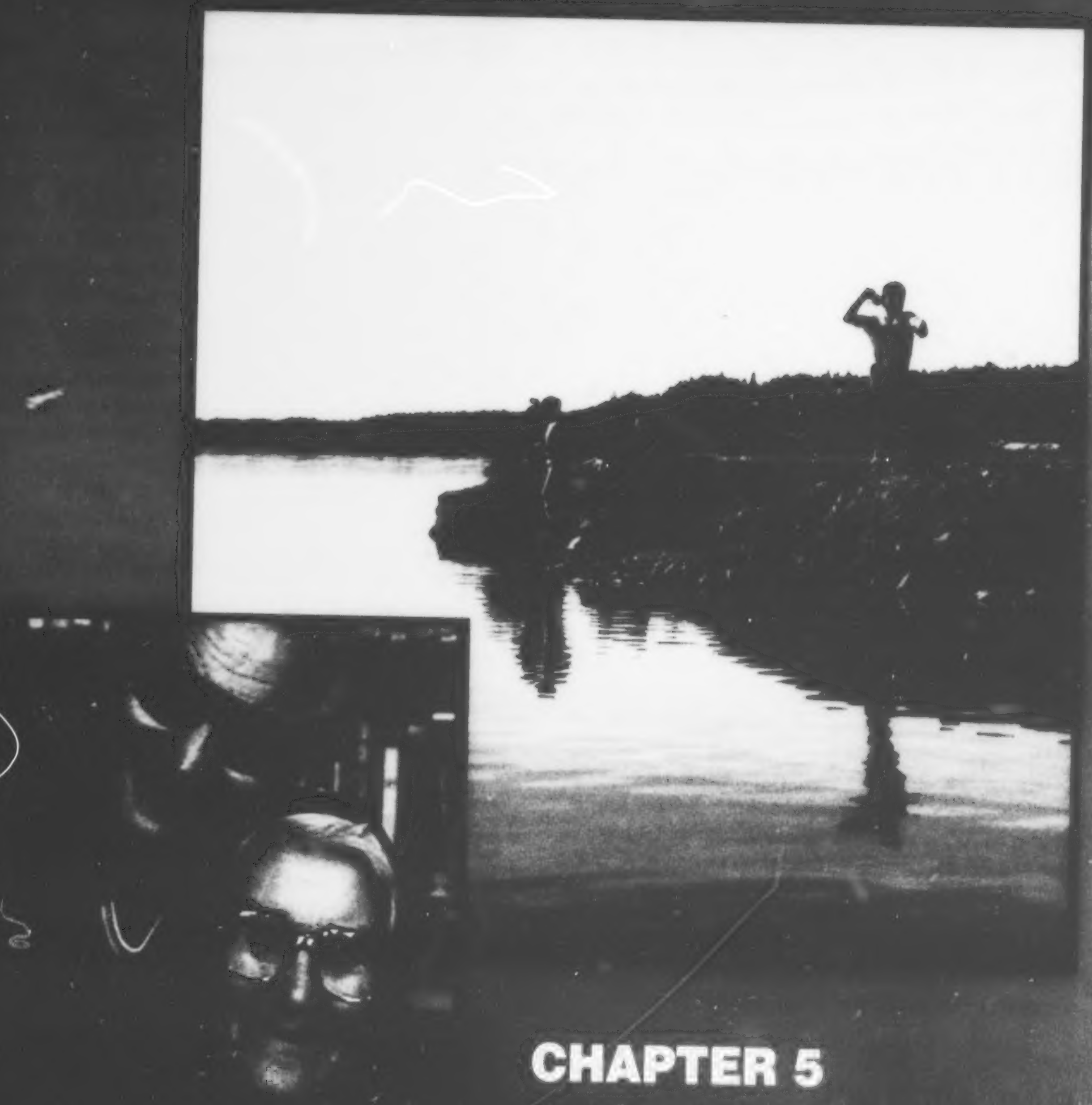


Effects of lake manipulation, however, were not entirely blameless in changing standing stocks in burrowing mayflies in SIL. After impoundment and diversion, water temperatures decreased in the large northern areas of the lake because warm Churchill River water was diverted away from these regions. This resulted in delayed ice break-up in the spring, reduction in length of the heating season, and lowered maximum water temperatures relative to regions upstream of the diversion. Burrowing mayflies were never abundant in these regions (because of the deep, cool nature of these regions even before diversion), so changes in standing stocks in these regions had little effect on total lake response. However, the period of below-average temperatures combined with cooling due to water diversion produced a different pattern of abundance for these regions than for the rest of the lake (Fig. 4.8). Although burrowing mayflies appear to be recovering in most regions of SIL, they have disappeared from all but the warmest, most sheltered northern areas of the lake.

Figure 4.8 *Comparison of Hexagenia Abundance in Northern Area of Southern Indian Lake to Total Lake, 1972 - 1987*



This study of the burrowing mayflies in SIL clearly illustrates the challenge in environmental monitoring to discriminate between natural variability and anthropogenic effects. Moreover, the nature of the problem is critical when dealing with populations at or near their limits of distribution, because such populations can be extremely sensitive to environmental change. Survey data alone, while usually inadequate for establishing cause and effect, are valuable for indicating areas that need attention in the course of a monitoring program. The results of post-development monitoring at SIL indicated a need to examine factors other than those related to hydroelectric development in order to explain patterns of abundance of burrowing mayflies. It was a combination of survey and experimental approaches which helped distinguish between the effects of lake manipulation and natural variability on the burrowing mayflies in SIL.



CHAPTER 5

FEMP REPORTING

INTRODUCTION

Advising the public of FEMP's results was one of FEMP's objectives. While public information is increasingly being recognized as an important principle in federal water policy (e.g. Currents of Change, Water 2020), there is little guidance available on the process for developing a public information program appropriate to the subject matter and target audience. Consequently, the FEMP public information program was developed on an ad hoc basis; this chapter discusses this process.

FEMP MESSAGE

As noted previously, the intent of FEMP was to partially address federal responsibilities under the NFA, by developing a scientific understanding of the environmental changes in the FEMP study area since the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project. The pursuit of this goal necessitated: 1) the scientific documentation of current conditions; 2) the review of all relevant data and environmental reports, especially historical; and 3) most importantly, an assessment of the adequacy of this information for the determination of environmental changes over time and ultimately of the environmental impacts of the LWCN project. Consequently, it was recognized that while reporting FEMP conclusions should be the major component of the FEMP public information program, it would also be necessary to report on the process by which these conclusions were obtained. This process included the documentation of when, and why, there were occasions where insufficient information precluded the drawing of scientifically supportable conclusions.

FEMP AUDIENCE

Determining the target audience, and in particular the information needs of this audience, was the other critical component of the FEMP public information program. The FEMP target audience was a diverse group, consisting of the native communities in the FEMP study area, lawyers, consultants, politicians, civil servants, scientists, and others with a general interest in environmental studies in northern Manitoba. A characteristic shared by most of this target audience was their lack of a scientific background in most, and often in any, of the scientific disciplines employed in FEMP. Thus, FEMP results had to be reported in a non-technical manner.

The most important group in the FEMP target audience, the residents of the 6 native communities in the FEMP study area, had additional, unique information needs. The importance of the changes in the environment to their lifestyles was reflected in their information needs; for example, mercury levels in the FEMP rivers and lakes, the source of their drinking water, was a particularly worrisome concern for many residents. The distinct cultural identity of these communities further distinguished them from the rest of the FEMP target audience. For example, elders, who are highly respected members of these communities, frequently only speak Cree; hence, part of the FEMP public information program had to be in this language.

COMMUNICATION PRODUCTS

How and what we choose to communicate is a reflection of our value system. The multiple value systems of the FEMP target audience, a reflection of their diverse cultural identities, necessitated the use of more than one communication technique. Two different types of communication products were produced: FEMP reports and a FEMP videotape.

FEMP Reports

The first FEMP public information product was the FEMP Report Series, which was initiated in 1987. The intent of this series was to disseminate the interim results of FEMP, as quickly as possible, primarily to the other members of the 4-party Program Advisory Board (PAB). More than 20 reports were produced in this series. The number of copies printed of each report varied from approximately 50 copies, for the more esoteric subjects, to approximately 250 copies, for the annual reports. A formal opportunity for PAB members to comment on the content of these reports, and indeed on all aspects of FEMP, was provided at the annual FEMP workshops.

The major FEMP public information product was the FEMP Final Report, consisting of this report and the accompanying technical appendices. This report is intended to address the information needs of the non-technical reader (by employing, for example the extensive use of graphics, a technical glossary, etc.), while the accompanying appendices provide full documentation on individual FEMP projects to meet the needs of the more technical reader. The FEMP Final Report provides a complete record of FEMP, which it is hoped, will enable the reader to obtain a full understanding of the FEMP results.

FEMP Videotape

While copies of all FEMP reports were made available to the native communities in the FEMP study area and to the Northern Flood Committee, it was recognized that this information had to be supplemented if the specific environmental concerns of the communities' residents were to be addressed, and in their own language. A videotape format was selected for the following reasons: 1) the oral form of Cree is more widely understood than the written form, (undoubtedly, the result of the traditional importance of oral story-telling in the native culture); 2) videotaped interviews would enable the communities' residents to relate, in their own words, their specific environmental concerns; and 3) previous experience with Cree language videotapes, on mercury, suggested that the videotape format was a successful method for communicating environmental information to native communities.

A Cree language videotape had been produced, on mercury in the mid 1980s, for Nelson House and South Indian Lake, as part of the public information program of the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA). A retrospective analysis of the CMMA's public information program (McKerness 1989a) concluded that the active involvement of the native communities was critical in the planning and implementation of the public information activities for them. A similar conclusion was reached during the production of the Cree language videotape, in the late 1980s, for the James Bay mercury program in Quebec.

In order to assess the level of community interest in a FEMP videotape, a pilot project was conducted in one of the 6 communities, selected at random. The Chief and Council of the Cross Lake Band were contacted, the concept explained to them, and their permission requested to film in their community. Permission was granted and Mrs R. Monias, the Cross Lake Key Communicator, was named as the designated contact person for the pilot project, which was begun in March 1990.

The pilot project was invaluable in: 1) identifying the environmental concerns in Cross Lake; 2) providing a sample tape of community interviews for previewing in the other 5 communities, when permission to film in their communities was being sought; 3) estimating the logistical requirements of filming in all 6 communities (e.g. cost, time); and 4) establishing an excellent working relationship with Mrs R. Monias, and through her, with the Key Communicators in the other communities.

The Key Communicators are community residents employed by the bands to advise their community about all NFA activities. The Key Communicators worked closely with the FEMP videotape crew on all aspects of the filming in their community, including: 1) scheduling the visits; 2) selecting community residents for the videotaped interviews; 3) arranging guides and boats for exterior shots; and 4) in general, providing logistical support (e.g. translation services). The greatest benefit, however, that resulted from working with the Key Communicators was that their involvement helped foster a climate of trust. (The community contact in South Indian Lake, a non-NFA community, was the mayor, who was equally helpful in the FEMP filming.)

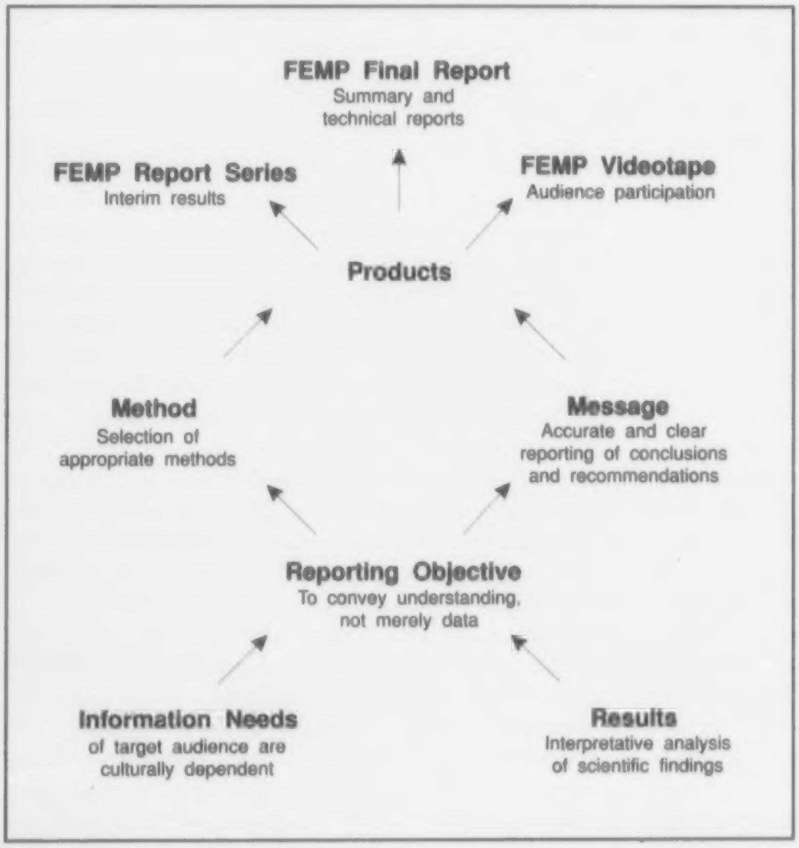
The FEMP videotape did not have a pre-prepared script; instead, the many hours of community interviews were carefully viewed to identify the major environmental concerns, based primarily on the number of times a concern was raised. Then, those FEMP results that were relevant to the identified concerns were selected for incorporation into the FEMP videotape. The interviews, usually accompanied by visuals to illustrate the speaker's comments, were interwoven with graphics and brief narratives on the relevant FEMP results to produce the FEMP videotape.

Copies of the English and Cree versions of the FEMP videotape were sent to all 6 communities. In addition, each community received an unedited VHS copy of all the tape shot in their community - the exterior shots, as well as the interviews. The broadcast-quality master tapes have been placed in government archives in Winnipeg to preserve this unique material for possible future users.

SUMMARY

Reporting on the results of the FEMP was a multi-step process that began with the critical step of identifying the information needs of the target audience. This process is outlined in Fig. 5.1.

Figure 5.1 FEMP Reporting Process


FEMP Final Report
Summary and technical reports
FEMP Report Series
Interim results
FEMP Videotape
Audience participation
Products
Method
Selection of appropriate methods
Message
Accurate and clear reporting of conclusions and recommendations
Reporting Objective
To convey understanding, not merely data
Information Needs
of target audience are culturally dependent
Results
Interpretative analysis of scientific findings

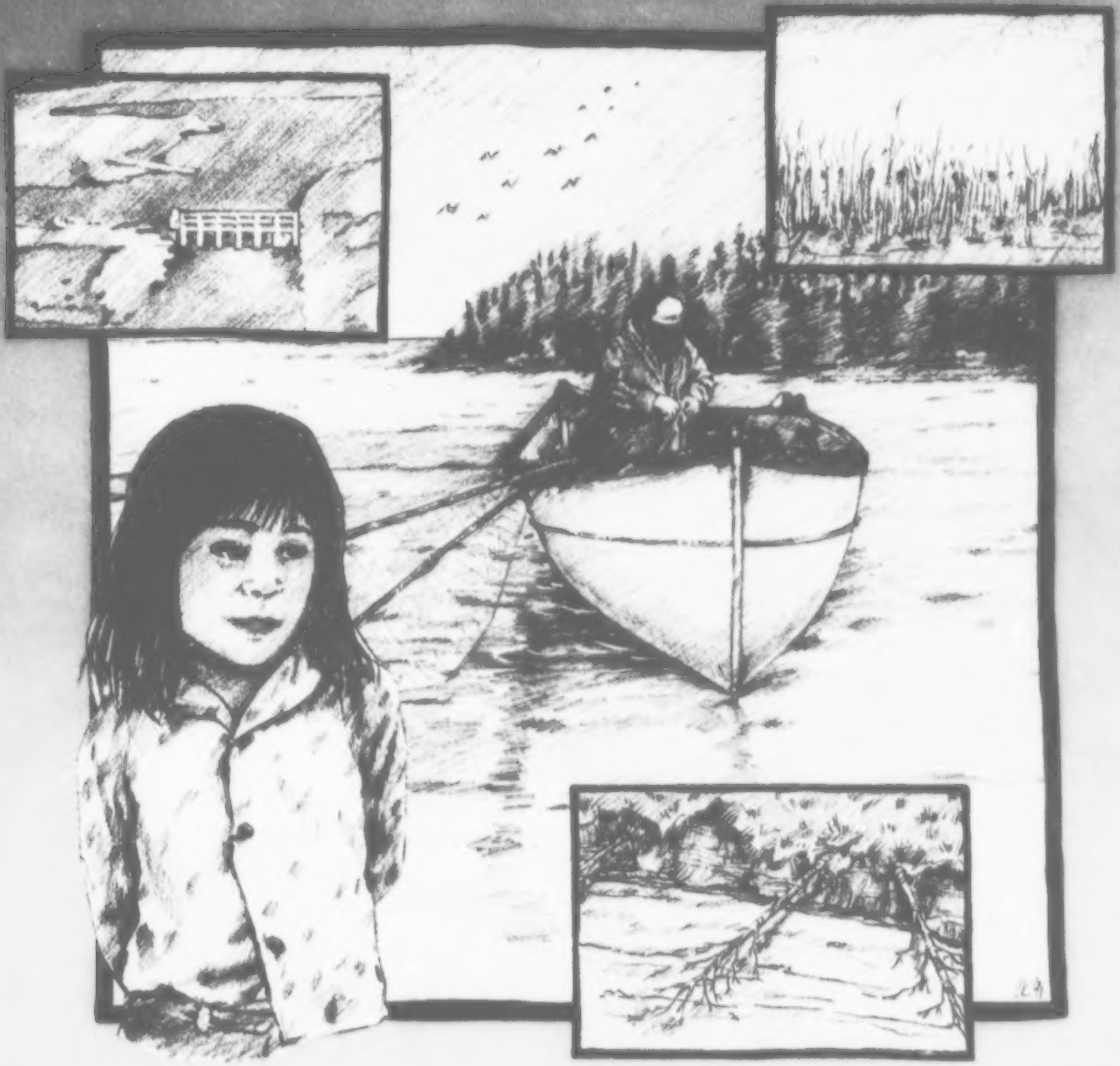
Volume

2

FEDERAL ECOLOGICAL MONITORING PROGRAM

Final Report

Volume 2



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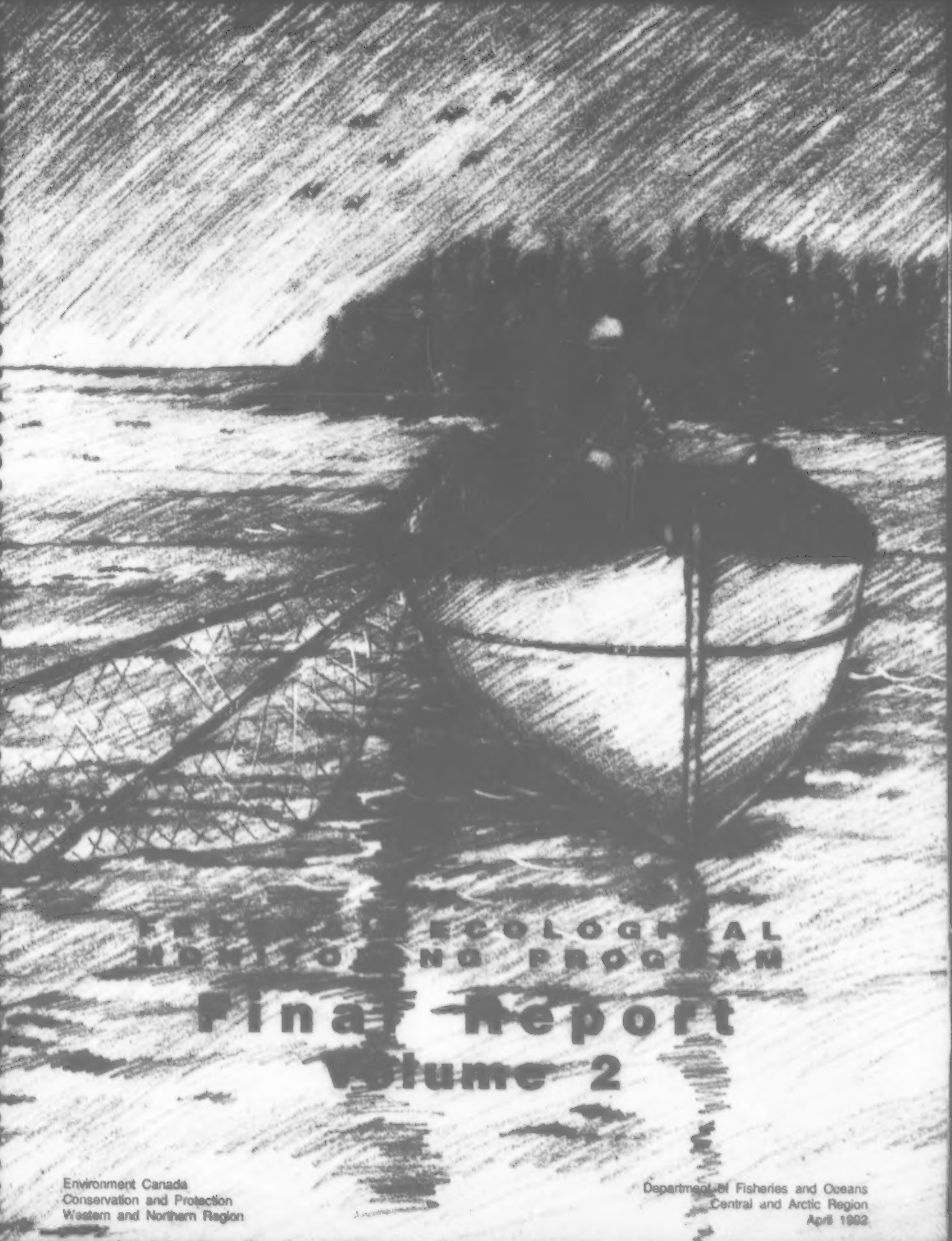

FEDERAL ECOLOGICAL MONITORING PROGRAM

Final Report

Volume 2

Environment Canada
Conservation and Protection
Western and Northern Region

Department of Fisheries and Oceans
Central and Arctic Region
April 1992

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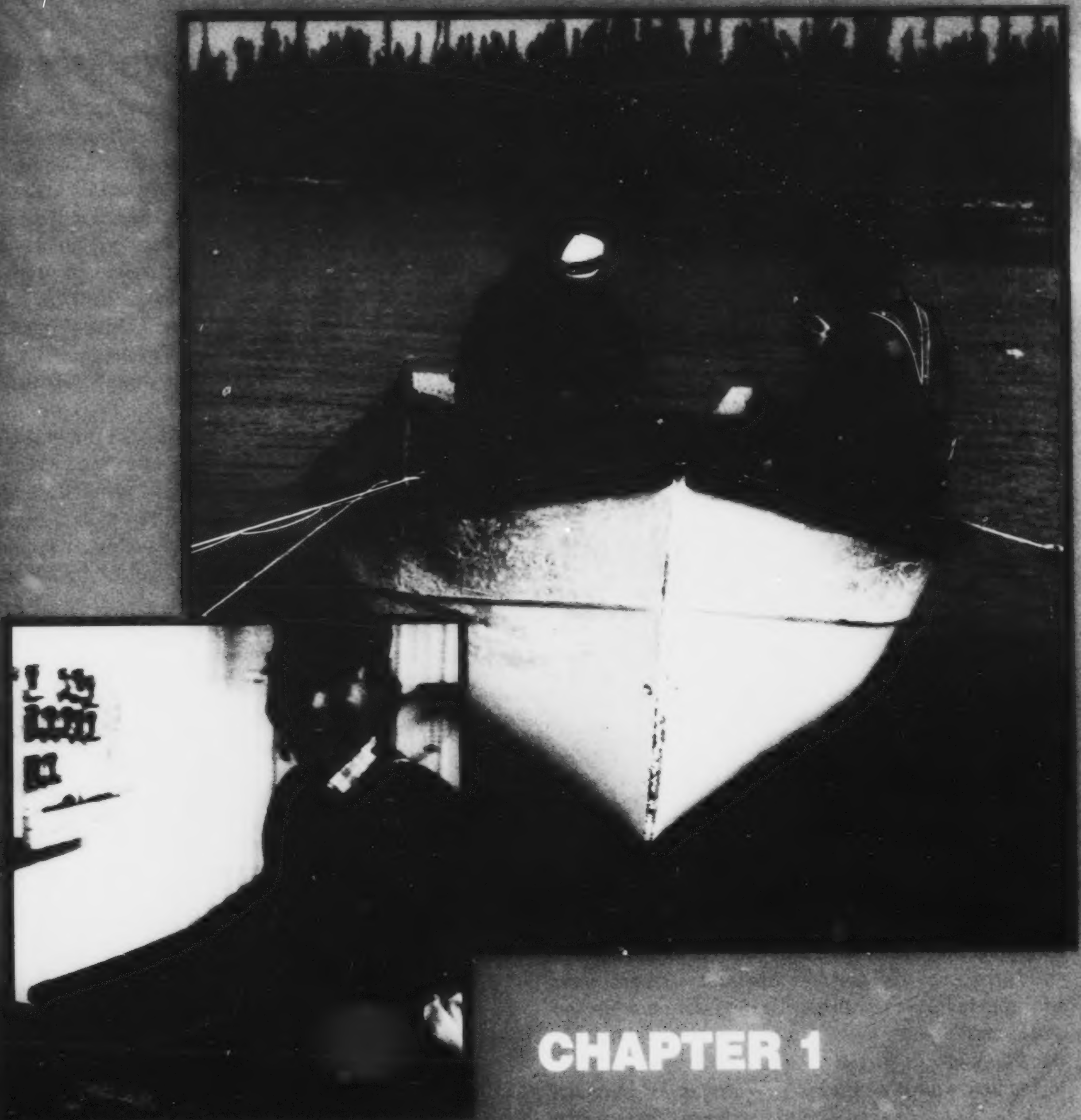


CHAPTER 1

RESOURCE HARVESTING

INTRODUCTION

FEMP focused on the physical, chemical and biological conditions in the FEMP study area; however, it was recognized that changes in these environmental conditions since the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project have also had major social and economic effects on the 6 native communities that traditionally utilized these waterways for livelihood and travel. A FEMP-sponsored study examined the effects of the LWCN project on the resource harvesting activities of the 5 Northern Flood Committee (NFC) communities (Usher and Weinstein 1991).

This report models resource harvesting systems, lists probable adverse project effects, and identifies impact indicators for social impact assessment of resource harvesting. It reviews available data for the five NFC communities regarding subsistence harvests, trapping, and commercial fishing, suggests the critical strengths and weaknesses of this database, and the requirements of a full social impact assessment. This report was intended to enhance our ability to monitor and predict the effects of the LWCN project and similar projects; it was not a social impact assessment per se, nor was it a substitute for one. Neither did it completely encapsulate all the resource harvesting activities of the NFC communities.

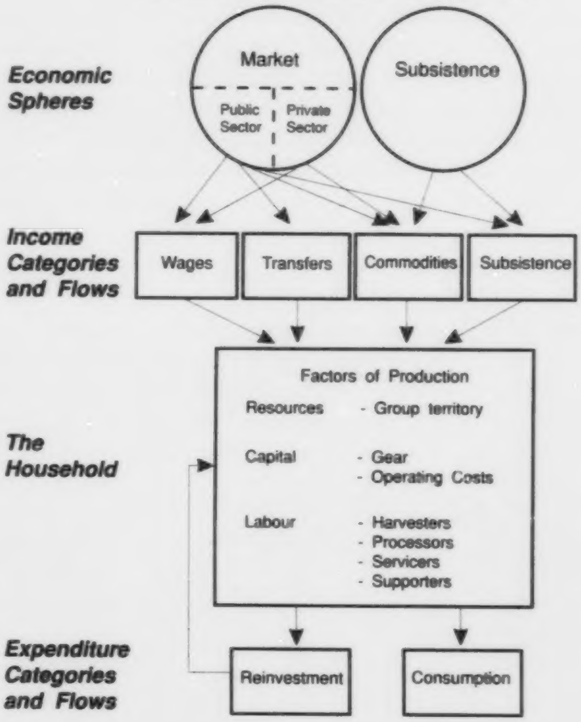
This chapter summarizes the results of the Usher and Weinstein report. It is augmented by information from a 1990 land use and occupancy study of South Indian Lake, a non-NFC native community located in the FEMP study area (Hrenchuk 1991).

SUBSISTENCE HARVESTING

Subsistence Activity

A distinctive characteristic of northern native communities is the place of resource harvesting as a central and integrative activity, and of subsistence as a socioeconomic system. Northern native community economies are recognized as being mixed, subsistence-based economies, in which the market and subsistence spheres are inextricably linked (Fig. 1.1). Subsistence, with its distinctive property and social relations, is an essential dynamic within the community culture and economy. Subsistence harvest and activity in this sense is not simply an addition to available income, but is inherent to the maintenance of social relations. Thus, subsistence-based economies may be affected by industrial development in a way which is fundamental, not peripheral, to their functioning.

Figure 1.1 The Household in the Mixed Economy, Market and Subsistence


Economic Spheres
Market
Public Sector
Private Sector
Subsistence
Income Categories and Flows
Wages
Transfers
Commodities
Subsistence
The Household
Factors of Production
Resources - Group territory
Capital - Gear - Operating Costs
Labour - Harvesters - Processors - Servicers - Supporters
Expenditure Categories and Flows
Reinvestment
Consumption

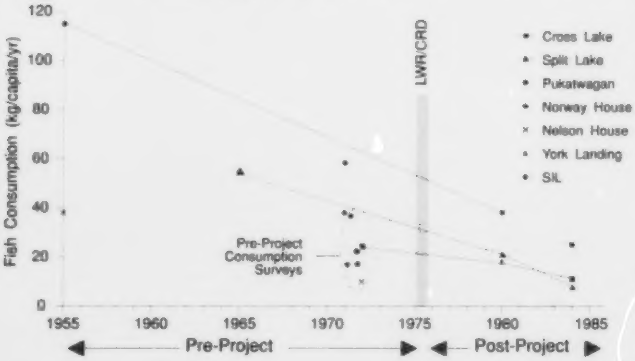
Changes in the location, abundance, and quality of water-dependent resources such as fish, aquatic fur bearers, and waterfowl can affect patterns of community land use and the viability and success of resource harvesting efforts. In order to assess the degree to which this has occurred, it was necessary to begin with an evaluation of subsistence harvesting data.

Subsistence Harvest Data

Data on household harvest by species, and if possible by edible weight, provide the most important indicator of subsistence income. Generally, these data result from surveys which are often done on the basis of informant recall. In the context of impact assessment, pre- and post-project data sets of adequate depth and consistency are required for comparative evaluation. It can be seen that data validity is dependent upon the extent to which standard methodological criteria have been followed and, furthermore, made explicit. By these standards, almost all of the existing estimates for northern Manitoba domestic harvests are of uncertain value.

For example, of the 21 estimates of per capita subsistence fish consumption for northern Manitoba cited by Usher and Weinstein, 11 were derived from surveys and 10 were speculative; 6 post-date the hydro project (Fig. 1.2). Many of these figures resulted from reiteration or extrapolation from results obtained through unacceptable and largely unspecified methods of earlier research. Thus any conclusions drawn from these data could not be regarded as robust. Furthermore, other potential indicators of subsistence fishing, such as participation, effort, and location are less easily quantified and are generally unavailable.

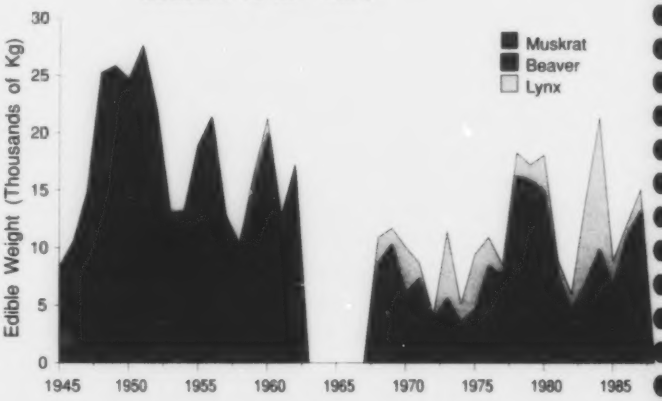
Figure 1.2 Annual Subsistence Fish Consumption (kg/capita) for Selected Northern Manitoba Communities, 1955 - 1984



Subsistence wildlife harvesting is comprised of big game, edible furbearers, waterfowl, and small game. Provincial records are the largest body of information about wildlife harvests, but they are of variable usefulness in evaluating subsistence harvesting. For example, conservation officer annual reports provide reasonably accurate data on pre-project ungulate harvest, and efforts have been made, in the 1980s, to acquire accurate data more systematically as part of the general ungulate management program in the province. However, the lack of accurate geographical references for the data on big game prevents the evaluation of the changes on a localized basis.

Edible furbearer harvests have been recorded indirectly through provincial records of furs sold, e.g. beaver, muskrat, and lynx. A recall harvest survey done in Split Lake and Cross Lake (Wagner 1985) provides a reference base for the provincial data. These statistics could be used to generate estimates of food harvest from edible furbearers over time (Fig. 1.3) and to evaluate pre- and post project harvests from affected and unaffected traplines.

Figure 1.3 Estimated Potential Food Harvests from Edible Furbearers Trapped on the Cross Lake Registered Trapline Section, 1945 - 1987



Pre- and post-project levels of subsistence harvesting of waterfowl and small game can not be compared because of lack of data.

Data on other potential indicators of subsistence wildlife harvesting activities (e.g. location, effort, and participation) are also lacking, for the 5 NFC communities. Some of this type of information is available for South Indian Lake from Hrenchuk's study. For example, an indication of the current level of participation in wildlife harvesting was given by the identification, from hunter interviews, of 232 prime sites for caribou, moose, muskrat and waterfowl in 39 of the community's 50 traplines.

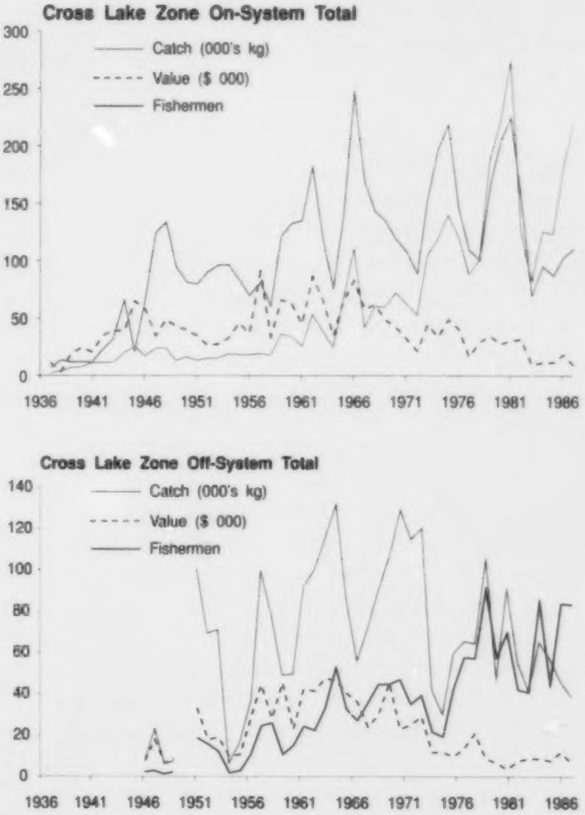
COMMERCIAL FISHING

When the modern commercial fishery was established in northern Manitoba, it was superimposed on the long-established Indian domestic fisheries. Since commercial fishing is strictly a licensed activity, in contrast to the case of subsistence harvesting, data have been collected on harvests since their inception. The first record of commercial fishing in the NFC area is from Sipiwesk Lake for the summer of 1937. The Southern Indian Lake fishery, the largest single fishery in northern Manitoba, began in 1942. Seventy-eight lakes were identified as having been commercially fished in the resource areas of the 5 NFC communities. Southern Indian Lake and 58 inland lakes have been fished commercially by South Indian Lake (Hrenchuk 1991).

Usher and Weinstein reviewed the available commercial data for its suitability in a social impact assessment, using: 1) weight of fish purchased; 2) dollar value to fishermen; and 3) number of licences issued, as indicators of volume, value, and participation respectively. On the basis of this review they concluded that the commercial fishing data were sufficiently comprehensive, uniform, and repetitive over many years to allow a preliminary assessment of the LWCN project's impact on catch and participation. These data indicated adverse impacts on the commercial fishing, for example: 1) the Cross Lake fishery experienced a sharp decline in production; 2) the Nelson House fishery has been partially contaminated by mercury; and 3) the cost of fishing increased at Norway House and possibly also at Split Lake. A more detailed economic valuation of the importance of commercial fishing in the FEMP study area could be assessed from the commercial fishing data, once appropriate adjustments to the data have been made to ensure constant dollars and comparable measures of weights. The adjusted values could be used as assessment indicators, by comparing data for on-system and off-system lakes (e.g. Fig. 1.4).

However, only some of the effects of the hydro project are revealed by the available commercial fishery data. For example, these data are inadequate for quantifying changes in cost and effort that can occur when fishermen respond to adverse biophysical effects by intensifying their efforts to maintain production, such as by setting more nets. Some of these changes in the Southern Indian Lake fishery have been documented by other FEMP sponsored studies that are reported on in chapter 2. Other changes, documented by Hrenchuk (1991), include low correspondence between pre- and post-impoundment preferred fishing sites, a reduction in the number of consistent net sites, and evidence of the diminution of lucrative pickerel fisheries.

Figure 1.4 Catch, Value, and Participation in the Cross Lake Commercial Fishery; for On-System and Off-System Lakes, 1936 - 1987



TRAPPING

Trapping has been integrated into the general pattern of resource harvesting of northern Manitoba communities since the time of European contact. Trapping allows for renewed contact with a land base, and for updating of the information base required for the successful harvest of wildlife. The opportunity to renew knowledge concerning the location, abundance, and movement of fur and non-fur species is essential in a hunting and trapping existence. Trapping is considered a traditional activity and, for many, it is part of a way of life. Although there are market and other economic considerations, the motivation for trapping in native communities does not primarily rely on profit. There is a desire to "come out ahead," but the provision of food or the fact of living in the bush may take priority.

Records of trapping harvests begin shortly after the inception of the registered trapline (RTL) program in the mid-1940s. There are about 226 traplines in the four RTL sections of the NFC communities, totalling 102,650 km^2. The South Indian Lake RTL section contains an additional 50 traplines with an area of approximately 35,000 km^2.

The fur record is split into three types: 1) 1950s, in which recorded fur sales are for the entire RTL; 2) 1960s to early 1980s, in which sales are recorded on the basis of individual traplines; and 3) 1984 onward, where a computerized record has been kept. Fur production and trapper participation data are available in considerable depth, both prior to and following the LWCN project (Fig. 1.5), and consequently may be useful in impact assessment. For example, the traplines can be aggregated by category of physical and biological impact, allowing the data to be used for hypothesis testing.

There are, however, potential difficulties in utilizing this record for impact assessment. Deviation from the record may occur where furs are not sold by the individual who trapped them, which seems likely within these community structures. Other uses, such as fur sales to tourists or furs used in clothing or craft manufacture, are excluded from the record. A major limitation in this data base, one that is shared with the commercial fishing data record, is that it contains no indicator of effort. Harvesters report that travel has become a major problem for some communities as a result of the LWCN project. However, increases in travel and cost are not measured in any institutional record-keeping system. The fur records are thus a necessary but not a sufficient tool for measuring change.

Additional data must be collected to supplement the fur data record in order to assess the importance of this activity and changes to it; one method would be trapper interviews such as those conducted in Hrenchuk's study of South Indian Lake. This study estimated that the sale of furs contributed approximately $206,000 in the 1987/88 season to the South Indian Lake economy, as well as providing furs for community use (e.g. crafts) and a source of meat, from the furbearers and from the animals hunted while in the process of trapping. The intensive and extensive use of the South Indian Lake resource area for trapping is evident from Fig. 1.6.

SOCIAL IMPACT ASSESSMENT AND RESOURCE HARVESTING

The social impact of industrial development on native communities, such as the LWCN project on the 6 native communities located in the FEMP study area, differs significantly from what its impact would be on southern Canadian communities, rural or urban. The content and pattern of social change itself, and the significance and distributional effects of this change, are distinctive in these communities because their socioeconomic characteristics, and the cultural and historical forces that created

Figure 1.5 Number of Registered Trappers and Value of Furs Harvested on Cross Lake, Norway House, Nelson House and Split Lake Registered Traplines, 1948 - 1988

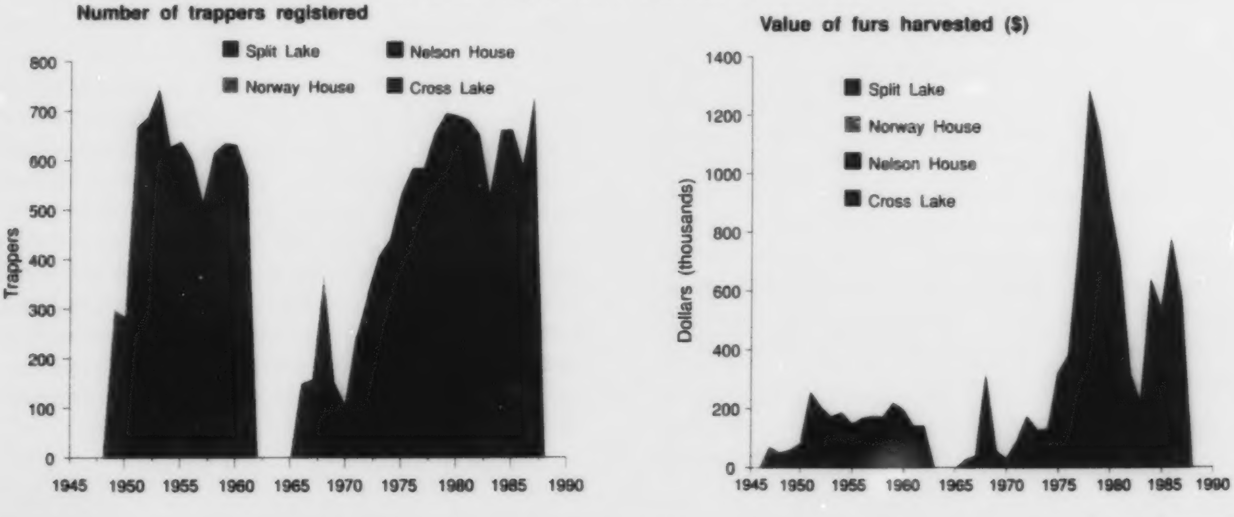
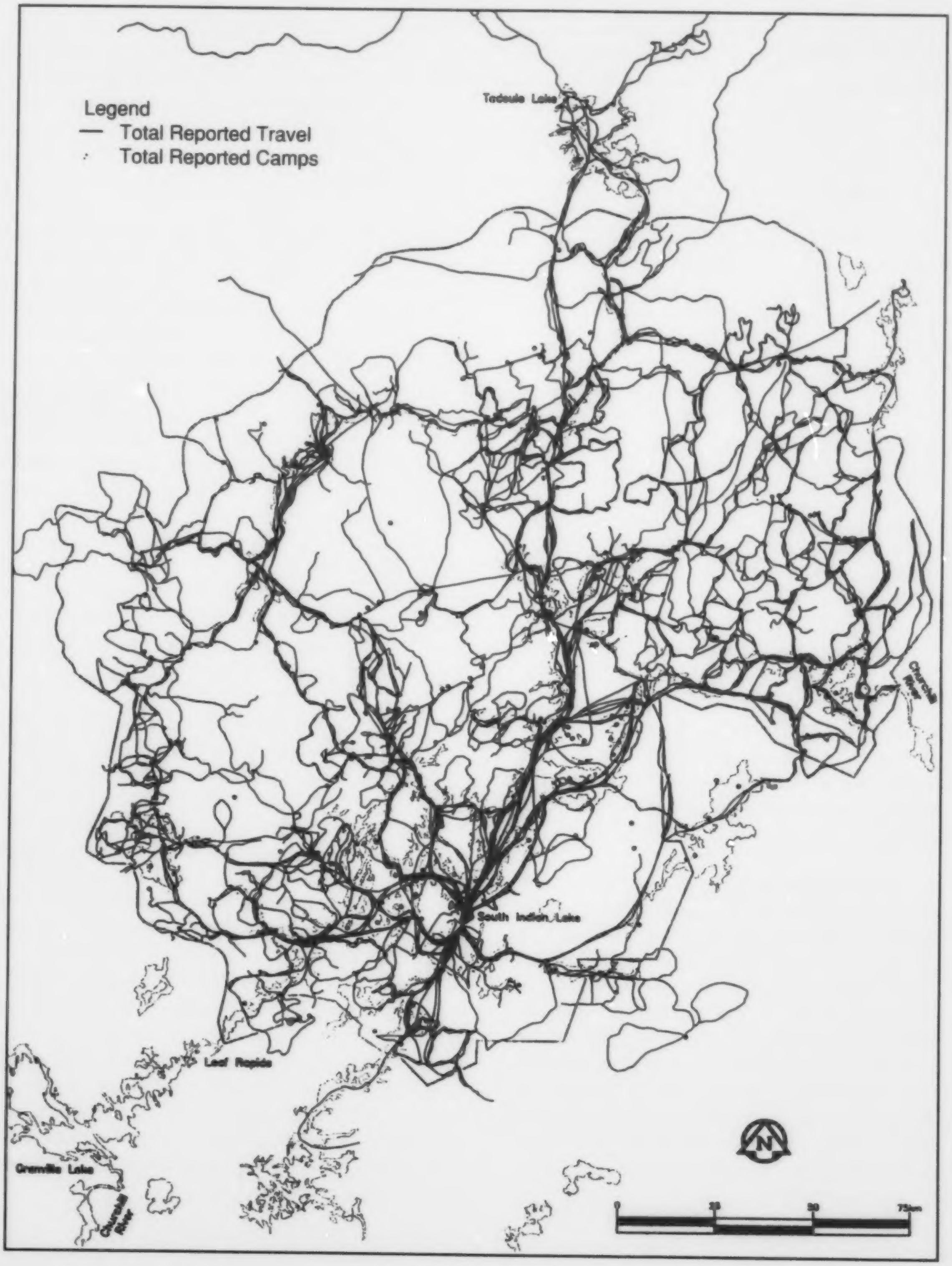


Figure 1.6 Total Reported Travel and Camps in the South Indian Lake Registered Trapline Area


Legend
— Total Reported Travel
· Total Reported Camps
Tadoule Lake
Churchill River
South Indian Lake
Leaf Rapids
Granville Lake
Churchill River
N
0
25
50
75km

them, are distinctive. Such differences, it is generally acknowledged, must be taken into account in social impact assessments (SIA).

However, this recognition in principle needs to be matched by more precise formulations of these differences in practice as the basis for selecting appropriate indicators. In the Usher and Weinstein study, institutional data on resource harvesting were reviewed to examine their potential as suitable social impact indicators. Interpretation of these data for this purpose, however, required three things: 1) a reliable model of resource harvesting systems (on their own and as part of a mixed subsistence-based economy); 2) sound historical knowledge of the evolution of these systems in each community (including their institutional manifestation in land tenure and resource management); and 3) an accurate record of the process and perception of changes induced by the LWCN project. These provide context as well as essential indications of significance, without which social impact cannot be assessed.

The two most readily available institutional data sets that can be used as impact indicators are those related to commercial fishing and trapping. These provide reasonably reliable indicators of harvest levels that can be identified (for the most part) at satisfactory levels of geographic detail, and which are of substantial historical depth. However, as noted, the fisheries data provide only limited information on harvesting effort, and the trapping data provide none at all. There are no other continuous records that can be used as impact indicators for resource harvesting. Estimates of subsistence harvesting are discontinuous in time and location, and idiosyncratic in method.

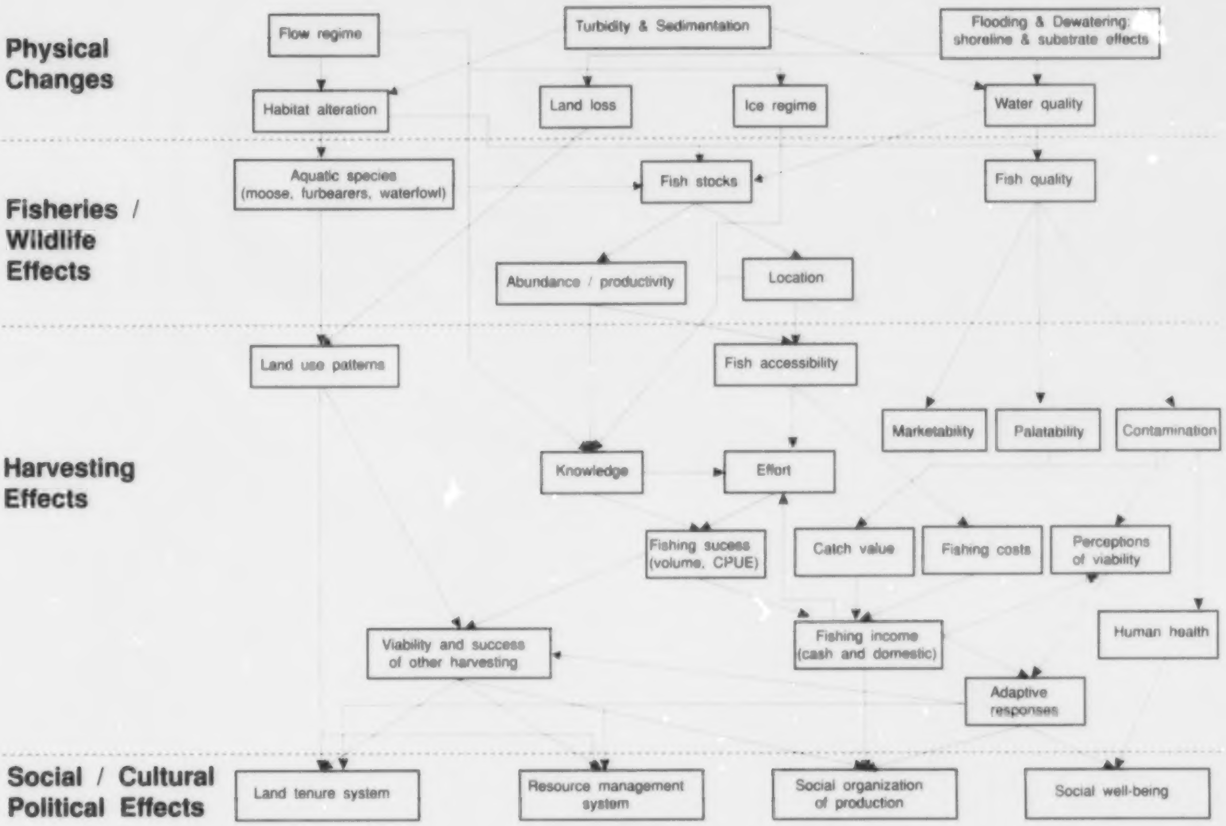
In view of the limited range of existing data, several additional lines of quantitative inquiry are required for social impact assessment. These include: 1) new or improved catch estimates for country food harvests, including fish, large and small game, and waterfowl; 2) improved effort estimates for the commercial fishery; 3) effort estimates for domestic fishing and hunting, and for trapping; 4) historic and recent patterns of land use and resource harvesting, geo-coded at least to the level of waterbody and trapline; and 5) dietary exposure to toxic substances (mercury in particular) in fish and other species, and changes in domestic consumption in response to perceived risks.

The successful employment of these formal, technical categories depends on them also being appropriate and recognizable categories in the minds of the affected harvesters. They cannot be imposed on each new situation on the sole grounds that they are technically sound or familiar. They must be discussed and pre-tested with harvesters. Harmonization of community and external technical categories requires disclosure and mutual understanding of their respective bases in experience, perception, and analysis.

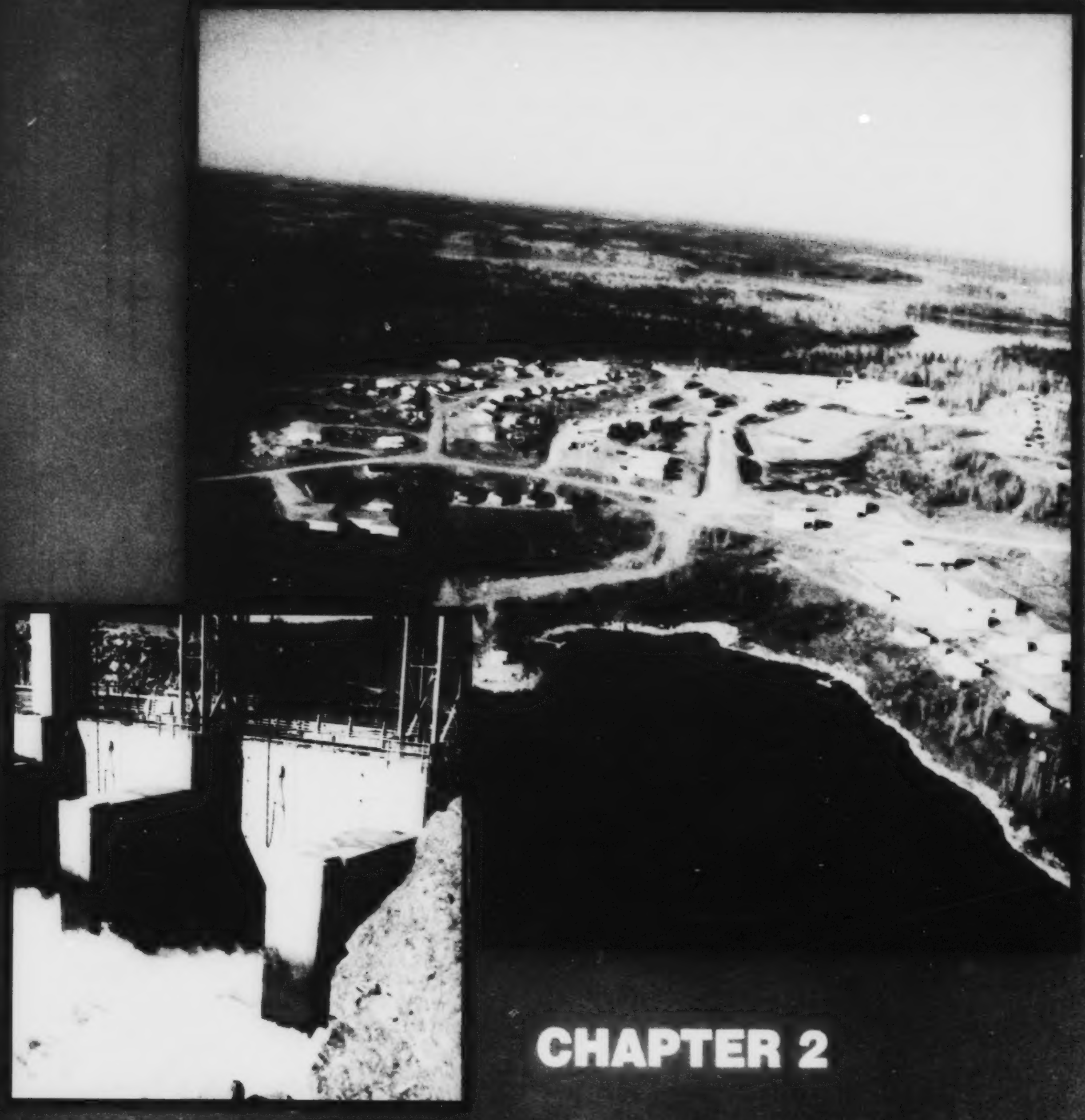
What is required is an account of harvesting now and in years past, of the changes in harvesting and of the explanations for these changes, and of the adaptive strategies by which people responded to them, to provide a context for interpreting the purely quantitative data. The type of information required includes: 1) the natural history of the land and the resources; 2) the land tenure and resource management system; 3) the social organization of production; 4) the functioning of the mixed, subsistence based-economy as a system; 5) the development of specific economic activities over time including their promotion and regulation by government; and 6) the emergence of reserve-based economics as enclaves. Finally, an assessment of the social impact of changes in resource harvesting and subsistence requires the compilation of standardized historical data sets of social indicators, coupled with documentation of community perceptions of impact.

Meeting this entire range of data needs would require a combination of survey, extended interview, participant observation, and archival research. The scale and complexity of the hydro impacts (Fig. 1.7) and of the communities affected by them would require some innovative approaches, including those which focus on particularly important or indicative subsystems. SIA, as outlined here, also requires the use of control groups (e.g. neighbouring communities unaffected by the project), imperfect as they may be given the limited range from which to select. Also, the investigation of cause and effect relationships through such comparative analysis requires much more precise historical documentation than is found in conventional SIA. Finally, substantial effort would be required, at an early stage of any SIA research program, on the identification of significant variables and indicators and development of working definitions, with respect to both change phenomena and the hypothesized agents of change.

Figure 1.7 Probable Effects of the LWCN Project on Resource Harvesting and Subsistence Activities in the FEMP Study Area, with Emphasis on the Fishery

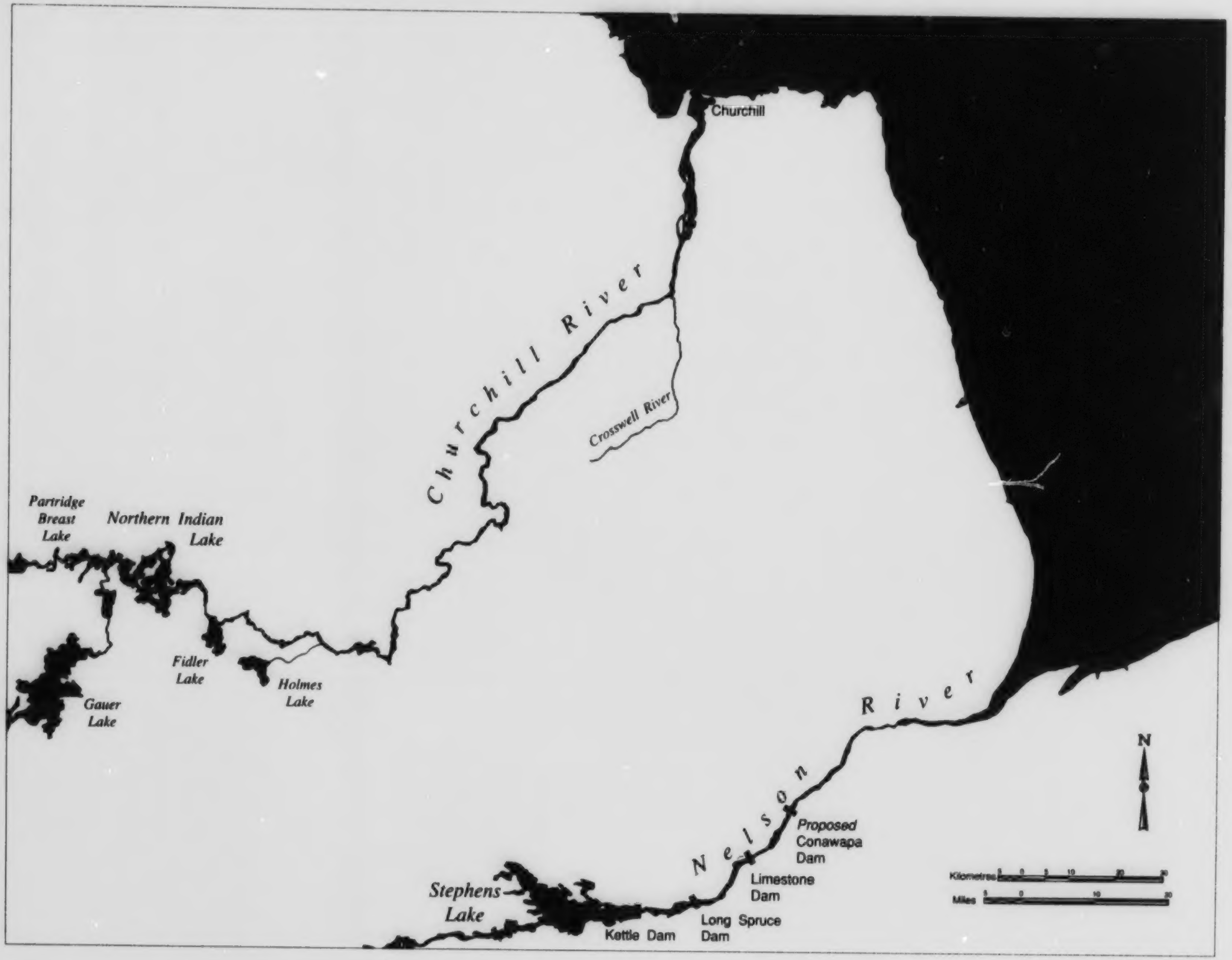

Physical Changes
Flow regime
Turbidity & Sedimentation
Flooding & Dewatering: shoreline & substrate effects
Habitat alteration
Land loss
Ice regime
Water quality
Fisheries / Wildlife Effects
Aquatic species (moose, furbearers, waterfowl)
Fish stocks
Fish quality
Abundance / productivity
Location
Harvesting Effects
Land use patterns
Fish accessibility
Marketability
Palatability
Contamination
Knowledge
Effort
Fishing sucess (volume, CPUE)
Catch value
Fishing costs
Perceptions of viability
Human health
Viability and success of other harvesting
Fishing income (cash and domestic)
Adaptive responses
Social / Cultural Political Effects
Land tenure system
Resource management system
Social organization of production
Social well-being

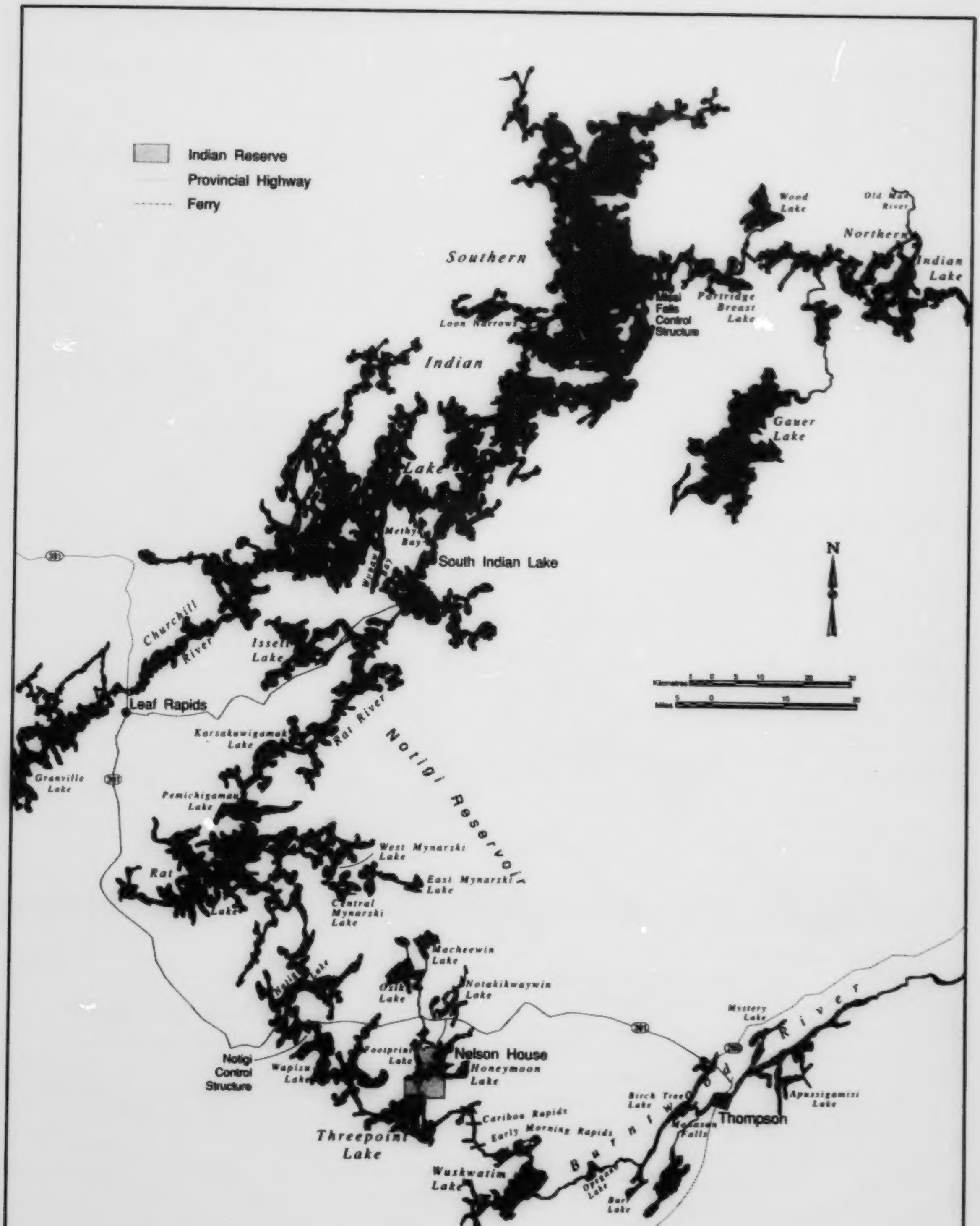
All of these considerations underline the importance, for a successful SIA, of research design and of extensive community involvement in that process. SIA must be community-based, not only in implementation and execution, but also in design and control. While external agencies can provide technical and financial resources, SIA which meets the requirements of public policy and scientific method will not occur until communities are institutionally enabled to initiate and direct it.

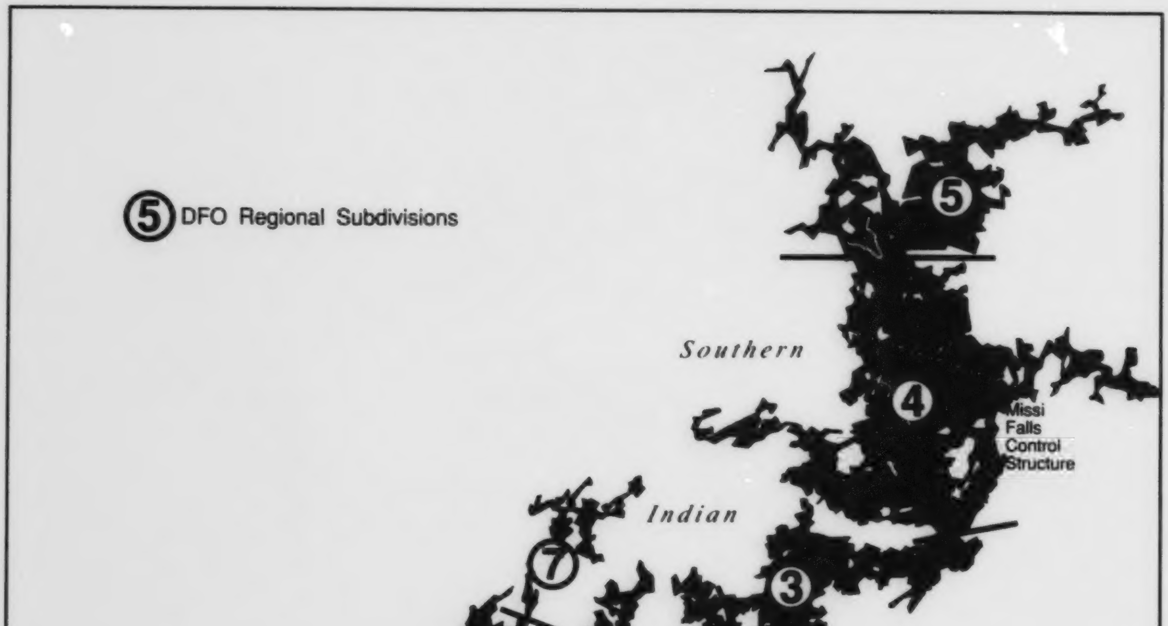


CHAPTER 2

SOUTHERN INDIAN LAKE AND THE CHURCHILL RIVER DIVERSION AREA


Churchill
Churchill River
Crosswell River
Partridge Breast Lake
Northern Indian Lake
Fidler Lake
Holmes Lake
Gauer Lake
Nelson River
Proposed Conawapa Dam
Limestone Dam
Long Spruce Dam
Kettle Dam
Stephens Lake
N
Kilometres 5 0 5 10 20 30
Miles 5 0 10 20


Indian Reserve
Provincial Highway
Ferry
Southern
Indian
Lake
Loon Narrows
Missi Falls Control Structure
Partridge Breast Lake
Wood Lake
Old Man River
Northern Indian Lake
Gauer Lake
Methye Bay
Wupaw Bay
South Indian Lake
N
Kilometres
Miles
391
Churchill River
Issett Lake
Leaf Rapids
Granville Lake
Rat River
Karsakuwigamak Lake
Notigi Reservoir
Pemichigamau Lake
West Mynarski Lake
East Mynarski Lake
Central Mynarski Lake
Rat Lake
Notigi Lake
Macheewin Lake
Notakikwaywin Lake
Osik Lake
Footprint Lake
Nelson House
Honeymoon Lake
Notigi Control Structure
Wapisu Lake
Threepoint Lake
Caribou Rapids
Early Morning Rapids
Wuskwatim Lake
Burntwood River
Opegano Lake
Birch Tree Lake
Mystery Lake
Apussigamisi Lake
Thompson
Manasan Falls
Burr Lake
6


⑤ DFO Regional Subdivisions
Southern
Indian
Lake
⑤
④
③
②
①
⓪
⑥
⑦
Missi Falls Control Structure
Methyl Bay
Wupaw Bay
South Indian Lake
Churchill River
Issett Lake
Leaf Rapids
Rat River
Karsakuwigamak Lake
Granville Lake
Pemichigamau Lake
N
Kilometres 5 0 5 10 20 30
Miles 5 0 10 20

MORPHOLOGY AND SEDIMENT REGIMES

Introduction

The greatest changes in the morphology and sediment regimes in the FEMP study area occurred in the area affected by the Churchill River Diversion (CRD). Three complementary approaches were taken to improve our understanding of these changes, as follows: 1) a review of all relevant literature; 2) studies to determine the feasibility of assessing morphological changes; and 3) preparation of a sediment budget.

The literature review revealed that the information on the morphological conditions in the CRD area was limited. For example, a pre-project shoreline classification scheme (LWCN 1975) did not include a number of features that are critical to an impact assessment of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project, such as inundated vegetation, floating organic material, cleared shorelines, or riprap. From the perspective of investigating sources of sediment production, this scheme is less than ideal due to its small scale, the lack of specific descriptions of shoreline stability (e.g. shoreline recession) or an assessment of the processes operating on the shoreline (e.g. wave action). More recent morphological investigations, which were based on the 1975 LWCN classification scheme, did not examine all of the CRD area nor did they quantify any of the observed morphological changes. Thus, it was decided to conduct two series of morphological feasibility studies, under FEMP, at a number of sites in the CRD area; one set categorized post-diversion shoreline characteristics and the other set focused on estimating sediment production at sites undergoing active erosion. Both sets of studies were based on air photo interpretation.

A number of investigations were pursued to enhance our knowledge of the sediment regime as follows: 1) collection of data on turbidity, non-filterable residue (NFR), and total dissolved solids (TDS) as part of the FEMP water quality program; 2) an assessment of sediment effects along the CRD; 3) preparation of an atlas of sediment sampling stations in the FEMP study area; and 4) an interagency comparison of field and laboratory procedures for determining suspended sediment concentrations. All of this sediment information, along with the results of the FEMP water budget (see volume 1, chapter 2), enabled the preparation of a sediment budget for the FEMP study area. A report on the sediment budget will be ready for publication in 1992.

This section summarizes the results of the FEMP investigations into the morphology and sediment regimes of the CRD area, by geographical area. A brief summary of the Department of Fisheries and Oceans' (DFO) pre-FEMP morphological and sediment investigations at Southern Indian Lake (SIL) is included for completeness. The section concludes with suggestions for future study.

The Lower Churchill River and Southern Indian Lake

Impoundment of Southern Indian Lake and diversion of the Churchill River down the Rat and Burntwood rivers greatly depleted the flows down the lower Churchill River. Comparison of 1969 and 1982/1984 air photos at 4 sites along the lower Churchill River showed an approximately 30% decrease in average channel width, resulting in: 1) desiccation of formerly extensive wetland areas; 2) exposure of large river bars and extensive areas of former river bed; 3) abandonment of former side channel areas; and 4) localized channel downcutting and bank erosion in former, apparently stable areas, causing locally significant sediment production.

The size of most tributary fans is now enlarged considerably. This appears to be caused by the exposure of previously submerged areas and, in a few locations, by the deposition of coarse textured materials transported by tributary streams. River depth has also been reduced but without comparative field surveys, the magnitude of this effect could not be determined.

In general, the observed morphological changes were relatively minor and progressing at very slow rates. This is primarily due to the many bedrock controls along the lower Churchill River and the incised nature of some channel reaches. Other factors contributing to the slow rates of morphological change are the many lakes along the mainstem river and its tributaries, which assure low rates of sediment transport and the harsh climate, which can result in slow rates of vegetation encroachment on to any abandoned active-channel zones.

While the changes in morphology in the lower Churchill River could have been predicted on the basis of experience from other case studies, in a qualitative manner, our ability to quantify the expected changes is far less certain, especially with respect to the prediction of subsequent physical and biological effects. Addressing these questions will require additional information such as: 1) the rate of sediment accumulation on tributary fans and the length of time for this process to stabilize; and 2) the percentage of side channels and wetland areas abandoned and changes in this percentage over time.

Immediately after the 3 meter impoundment of SIL in 1975/1976, the percentage of bedrock-controlled shorelines dropped from 76% to 14%. Most of the new shorelines were in fine grained, permanently frozen, ice-rich overburden consisting primarily of silt, clay and organics. As a result, there was considerable shoreline erosion; for example, erosion rates as high as 23 $m^3 \cdot m^{-1}$ of shoreline per year have been observed. (A predictive model for annual erosion rates at SIL was developed by DFO, based on the results from 20 shoreline monitoring sites, located in a variety of shoreline material and covering a wide range of wave exposure, height, and shoreline configurations. Because it automatically corrects for lake size, this model should be applicable to those lakes in the FEMP study area where the shoreline materials are similar to SIL, such as Footprint, Threepoint, and Wuskwatim. However, the SIL model has yet to be tested on other lakes.)

Most of the eroded mineral materials from SIL shorelines were deposited within a few hundred meters of the shore. However, there is evidence that these near shore deposits might be temporary and the sediments could eventually be remobilized and become part of the lake's general suspended load. At one site where shoreline erosion ceased after encountering bedrock, the recent near shore deposits disappeared over a period of 3 years.

The increased input of sediment into SIL raised sediment concentrations from about 5 $mg \cdot L^{-1}$, pre-impoundment values, to 30-50 $mg.L^{-1}$, post-impoundment. It also increased sediment output from SIL from about 120 000 tonnes in 1975, to 400 000 tonnes in 1976, 600 000 tonnes in 1977 and 550 000 tonnes in 1978. Most of this sediment outflow was transported to the upper reaches of the CRD, where much of it was lost in the upper Notigi Reservoir. Estimates of current sediment output from SIL will be available once the FEMP sediment budget is completed.

Notigi Reservoir Area

The Churchill River was diverted by means of a 9 km channel that was excavated from South Bay, at the southern end of Southern Indian Lake, to Issett Lake in the headwaters of the Rat River. In its natural state, the Rat River, like the Burntwood River, was mostly bedrock controlled, with stable shorelines. Lakes were an integral part of both rivers, with several river reaches consisting mainly of lakes, connected by short riverine segments. The Rat and Burntwood rivers are located in an area of low, undulating relief; vast, poorly drained areas of organic terrain are interspersed with some bedrock outcrops and other glacial features.

With the diversion of the Churchill River and the installation of the Notigi Control Structure, the series of small lakes along the Rat River was flooded to form Notigi Reservoir. The surface area of Notigi Reservoir, of 733 km^2, is substantially greater than the combined pre-development area of the incorporated lakes (e.g. Karsakuwigamak) of 182 km^2; the remaining area, 551 km^2, consists of flooded terrestrial terrain. Dead standing trees and floating peat bogs were prevalent through Notigi Reservoir immediately following diversion.

Notigi Reservoir, in particular the northern part of the reservoir embracing Karsakuwigamak and Pemichigamau lakes, is thought to be acting as a sediment sink, trapping most of the sediment output from SIL. In the lower part of the reservoir, formerly Notigi Lake, there is sediment deposition resulting from local shoreline erosion. There is some suggestion that shoreline erosion in this part of the reservoir may be increasing, as evidenced by the significantly greater turbidity levels in 1987 than those measured in the late 1970s. The decay and removal of inundated vegetation over time may be facilitating this apparent increase in erosion.

Footprint Lake Area

Interpretation of 1985 air photos for Footprint Lake and Honeymoon Lake, a small lake connected by flooding to Footprint Lake, showed that 37% of the combined shorelines contained standing debris, 47% had been cleared, and 55% were areas with floating vegetation or shallow water (Fig. 2.1). Analysis of 1972 air photos showed that approximately 75% of the shorelines at that time did not consist of any of the 5 categories used in the FEMP feasibility study (e.g. floating debris); these shorelines were categorized as unclassified. Consequently, it was not possible to conduct a comprehensive analysis of the changes from 1972 to 1985 in shoreline characteristics on the basis of this feasibility study. However, comparison of the classified shorelines showed the following changes: 1) an increase in shorelines with shallow water or floating vegetation from 14 km to 83 km; 2) an increase in shorelines with standing debris from 0.2 km to 56 km; 3) an increase in eroding shorelines from 4 km to 40 km, indicating the potential for widespread sediment production; and 4) an increase in cleared shorelines from 4 km to 71 km, the result of an attempt to reduce one negative impact of flooding.

Figure 2.1 Lengths of Coded Shoreline Types on Footprint, Honeymoon, and Threepoint Lakes, 1972 and 1985

	Footprint and Honeymoon Lakes 1972		Footprint and Honeymoon Lakes 1985		Threepoint Lake 1985	
Shoreline Type	**m**	**%**	**m**	**%**	**m**	**%**
C	410	0.5	8,800	5.8	0	0.0
CD	0	0.0	730	0.5	0	0.0
CDF	0	0.0	14,440	9.6	0	0.0
CE	3,930	5.2	7,120	4.7	1,540	0.8
CED	0	0.0	980	0.7	470	0.3
CEDF	0	0.0	330	0.2	0	0.0
CEF	0	0.0	3,880	2.6	1,700	0.9
CF	0	0.0	31,960	21.2	4,730	2.6
CR	0	0.0	90	0.1	0	0.0
CRE	0	0.0	2,600	1.7	0	0.0
D	0	0.0	7,040	4.7	27,510	15.1
DF	0	0.0	23,200	15.4	87,210	47.9
E	0	0.0	14,590	9.7	490	0.3
ED	230	0.3	7,580	5.0	39,870	21.9
EDF	0	0.0	1,430	0.9	3,380	1.9
EF	0	0.0	1,400	0.9	0	0.0
F	14,200	18.7	6,770	4.5	6,280	3.4
R	0	0.0	230	0.2	0	0.0
U	57,120	75.3	17,570	11.7	8,960	4.9

Classification System Used to Map the Distribution of Shore Zone Characteristics

C	Cleared of standing trees (debris may still be piled on the ground)
D	Standing inundated debris or vegetation in the nearshore or backshore area
F	Floating debris or organic matter in water; areas with shallow water depths
E	Eroding areas of shoreline as indicated by the absence of vegetation, the presence of foreshore sediment deposits, sediment plumes, mass-wasting features (such as rotational failures), etc.
R	Rip-rap
U	Unclassified shorelines not containing any of the above features.

NOTE:Shore zone characteristics are not mutually exclusive

A comparative analysis of the 1972 and 1985 air photos, along with topographic data, was used to generate quantitative estimates of sediment production at an actively eroding site, a small island near the southern shore of Footprint Lake, immediately east of Footprint River. It was found that the island's area decreased by approximately 6200 m^2 (from 9500 to 3300 m^2) and that the shoreline perimeter decreased by approximately 170 m (from 390 to 220 m). If it is assumed that 50% of the shoreline recession was due to erosion, rather than inundation, and that the depth of eroded sediment was 2 m, the total volume of material removed from this site would be in the order of 6000 m^3 or 27 m^3 per meter of present shoreline length. If it is further assumed that the majority of this erosion occurred in the 9-year period between 1977 and 1985, this would correspond to an annual rate of sediment production of 3 m^3 per meter of shoreline eroded. As both the shoreline heights and the percentage of bank recession due to erosion were likely under-estimated, the confirmed volume of material eroded from this site is a minimum estimate. Field investigations would be required to improve upon this estimate (e.g. determination of the ice content of the eroded shorelines).

It should be noted that the rate of sediment production at this island is not typical of all of Footprint Lake; for example other sites along the shoreline show no apparent change in shoreline position from 1972 to 1985. Photography taken in 1985 indicated generally much more turbid water conditions than in 1972, with localized sediment plumes extending off many of the west-facing shorelines. Comparison of 1972 and 1954 photography indicated no detectable change in shoreline position had occurred during this period; however there were some localized shoreline erosion sites, such as along the western shore of the first bay east of Footprint River.

Threepoint Lake

Analysis of 1985 air photos for Threepoint Lake showed that standing inundated vegetation or debris comprised almost 87% of the total lake shoreline; this is comparable to the total (84%) percentage of shorelines of Footprint and Honeymoon lakes that contained standing inundated vegetation or debris or that had been cleared. The percentage distribution of areas with floating vegetation or shallow water for Threepoint Lake was also similar to those of Footprint and Honeymoon lakes, with 56% and 55% respectively (Fig. 2.1).

Data on sediment related parameters such as turbidity, total dissolved solids (TDS) and non-filterable residue (NFR) were collected at 4 sites in the Threepoint Lake area as part of the FEMP water quality study. Fig. 2.2 summarizes these data, along with data on colour. (Colour is determined not by the presence of sediment, but rather by the presence of naturally occurring acids; these data are included in Fig. 2.2 because colour, like sediment, affects the aesthetic enjoyment of water.)

The post-development mean turbidity levels for the Burntwood River above Threepoint Lake were higher than for the other natural site in this area, the Footprint River above Footprint Lake; however, neither of the two natural sites showed any substantial difference from the pre-development period. Values for the natural Burntwood River site for the FEMP study period and the 1971 - 1974 pre-development period were 19 NTU and 14 NTU respectively, while the corresponding values for the natural Footprint River site were 9 NTU and 7 NTU.

The mean post-development turbidity levels for the Rat River above Threepoint Lake were marginally lower than for the natural Burntwood River site, while the mean post development turbidity value for the Burntwood River at the outlet of Threepoint Lake was intermediate between the two upstream sites. In contrast to the natural sites, there was an almost three-fold increase in mean turbidity levels at the Rat River site above Threepoint Lake, from 5 NTU in the 1971 - 1974 period to 17 NTU in the 1987 - 1989 FEMP study period. Lack of pre-development data for the Burntwood River site at the outlet of Threepoint Lake prevented a quantitative analysis of changes in turbidity here; however it is likely that turbidity levels also increased at this site.

Figure 2.2 Turbidity, Total Dissolved Solids, Non-Filterable Residue, and Colour for the Threepoint Lake Area, 1986 - 1989

Variable	Type	Units	Mean	SD	Max.	Min.
Burntwood River above Threepoint Lake [1]						
Turbidity	field	NTU	23.$^{+}$	7.	47.$^{+}$	12.$^{+}$
	lab	NTU	19.$^{+}$	4.	27.$^{+}$	13.$^{+}$
TDS		mg·L^{-1}	57.	10.	71.	25.
NFR	total	mg·L^{-1}	14.	7.	33.	6.
	fixed	mg·L^{-1}	11.	5.	27.	4.
Colour	true	relative	41.$^{+}$	10.	55.$^{+}$	25.$^{+}$
Rat River above Threepoint Lake [2]						
Turbidity	field	NTU	19.$^{+}$	8.	48.$^{+}$	9.$^{+}$
	lab	NTU	17.$^{+}$	8.	46.$^{+}$	11.$^{+}$
TDS		mg·L^{-1}	53.	4.	62.	46.
NFR	total	mg·L^{-1}	10.	7.	42.	5.
	fixed	mg·L^{-1}	9.	6.	38.	4.
Colour	true	relative	14.	4.	20.$^{+}$	5.
Footprint River above Footprint Lake [1]						
Turbidity	field	NTU	12.$^{+}$	6.	36.$^{+}$	6.$^{+}$
	lab	NTU	9.$^{+}$	3.	18.$^{+}$	4.
TDS		mg·L^{-1}	99.	26.	147.	41.
NFR	total	mg·L^{-1}	8.	4.	20.	4.
	fixed	mg·L^{-1}	6.	3.	16.	2.
Colour	true	relative	20.$^{+}$	8.	40.$^{+}$	10.
Burntwood River at outlet of Threepoint Lake [2]						
Turbidity	field	NTU	23.$^{+}$	25.	160.$^{+,++}$	10.$^{+}$
	lab	NTU	20.$^{+}$	21.	140.$^{+,++}$	8.$^{+}$
TDS		mg·L^{-1}	54.	4.	62.	47.
NFR	total	mg·L^{-1}	12.	21.	134.	3.
	fixed	mg·L^{-1}	11.	21.	126.	2.
Colour	true	relative	16.$^{+}$	5.	35.$^{+}$	10.

1 Sample period; May 1987 - Mar. 1989
2 Sample period; Sept. 1986 - Oct. 1989

Footnotes
$^{+}$ Exceeds limit for drinking water
$^{++}$ Exceeds limit for protection of aquatic life
Exceedences in the "Max." column indicates occasional exceedences.

Threepoint Lake to Wuskwatim Lake

The shoreline along the Burntwood River between Threepoint and Wuskwatim lakes is relatively steeply sloping while the valley flat is narrow and discontinuous; thus in most places the river is confined by the valley walls. An extensive series of bedrock controlled rapids is located in this section. Five segments of the Burntwood River in the vicinity of the major rapids (e.g. Caribou Rapids, Early Morning Rapids) were selected for air photo analysis; these segments focused on the most actively eroding sites along this reach of river.

Active channel areas were calculated for each channel segment from a series of air photos (Fig. 2.3). These results indicated that changes in surface areas between 1970 and 1972 were small and likely reflected the imprecision associated with the measurement technique as well as the slightly larger river discharge in 1972. Changes in area between 1970 and 1981 and 1985 were substantial, with active channel increasing in area by 23% and 36%, respectively. This increase in surface area reflected both the extensive shoreline erosion that occurred in the vicinity of the rapids and the inundation of low-lying sections of the valley flat and adjacent valley walls.

Figure 2.3 Estimated Changes in Active Channel Area and Volume of River Bank Erosion in the Vicinity of Gods, Caribou and Early Morning Rapids

Surface area of river in	*Total (m^2)*	*Change in surface area river in*	*(m^2)*
1970	633,000	1970-1972	9,500
1972	642,500	1970-1981	143,800
1981	776,800	1970-1985	230,200
1985	863,200	1981-1985	86,400

Length of actively eroding bank: 5,700 m

Total bank length: 10,960 m

Percent of bank actively eroding: 52%

Estimated increase in surface area due to bank erosion (m^2)	low	high
1970-1981	37,180	74,360
1981-1985	21,880	43,750

Estimated volume of eroded material (m^3)	low	high
1970-1981	74,360	297,440
1981-1985	43,760	175,000

Average annual sediment production (tonnes/year)	low	high
1977-1981	16,400	65,500
1981-1985	12,000	48,000

On the basis of air photo interpretation, it was estimated that approximately 50% of the total shoreline in the 5 river segments were actively eroding. Preliminary estimates of the volume of eroded material were calculated on the basis of certain assumptions (e.g. "low" and "high" estimates of the heights of eroding banks of 2 and 4 meters, respectively). On the basis of these assumptions, it was calculated that in the period 1977 to 1981, the average annual sediment load delivered to the diversion route from this reach was in the order of 1.6 to 6.5 x 10^4 tonnes per year. Calculated sediment delivery in the period 1981 to 1985 had a slightly smaller value of 1.2 to 4.8 x 10^4 tonnes per year.

Air photo analysis of Wuskwatim Lake indicated that no detectable change in shoreline position had occurred in the period between 1955 and 1972. Post-diversion photos taken in 1978 showed extensive sediment plumes along the near shore areas indicating that active erosion was occurring. Photography taken in 1985 indicated extensive areas of the southern end of Wuskwatim Lake were still undergoing active erosion. Eroded trees littered the near shore area and highly turbid water conditions occurred along the foreshore.

The volume of eroded material from low-lying sites was estimated to be approximately 6 m^3 per meter of shoreline. Shoreline retreat for shorelines with much higher bank heights was estimated to be slower than for shorelines from low-lying sites; however, given the larger amount of material which must be eroded from these higher relief sites, the inferred slower rates of bank retreat does not necessarily mean that smaller volumes of sediment are being produced from these areas. In comparison to southern Footprint Lake, shoreline erosion volumes may, nevertheless, be somewhat smaller, possibly reflecting both material characteristics and orientation of the lakeshore in relation to the prevailing wind direction.

As might be expected from the large estimated volumes of eroded material being produced along the diversion route, both at localized sites of active erosion such as rapids and the more widespread lakeshore erosion such as at Wuskwatim Lake, an examination of Landsat images from 1973 to 1986 suggest that the Burntwood River and on-route lakes downstream of Threepoint Lake are more turbid after diversion. In addition, there were some indications of increasing turbidity with distance along the diversion route. However, the large increase in river flows along the diversion route has meant that the post-diversion sediment concentrations are not greatly different from pre-diversion values; the major pre- to post-diversion change was in sediment tonnages, not concentration.

Thompson

No air photo interpretation was conducted of the Thompson area in the FEMP morphological feasibility study and consequently no preliminary assessment of the morphological changes is available for this site. However, this site has the best turbidity data record of any site in the FEMP study area, with data collected before diversion, during construction, and immediately after full diversion, as well as for the FEMP study period (Fig. 2.4 and 2.5).

Figure 2.4 Turbidity, Total Dissolved Solids, Non-Filterable Residue, and Colour for Thompson, 1987 - 1989

Variable	Type	Units	Mean	SD.	Max.	Min.
Turbidity	field	NTU	31.$^{+}$	9.	65.$^{+,++}$	18.$^{+}$
	lab	NTU	27.$^{+}$	6.	37.$^{+}$	15.$^{+}$
TDS		mg·L^{-1}	60.	4.	68.	54.
NFR	total	mg·L^{-1}	17.	5.	32.	7.
	fixed	mg·L^{-1}	15.	5.	29.	6.
Colour	true	relative	21.$^{+}$	5.	30.$^{+}$	10.

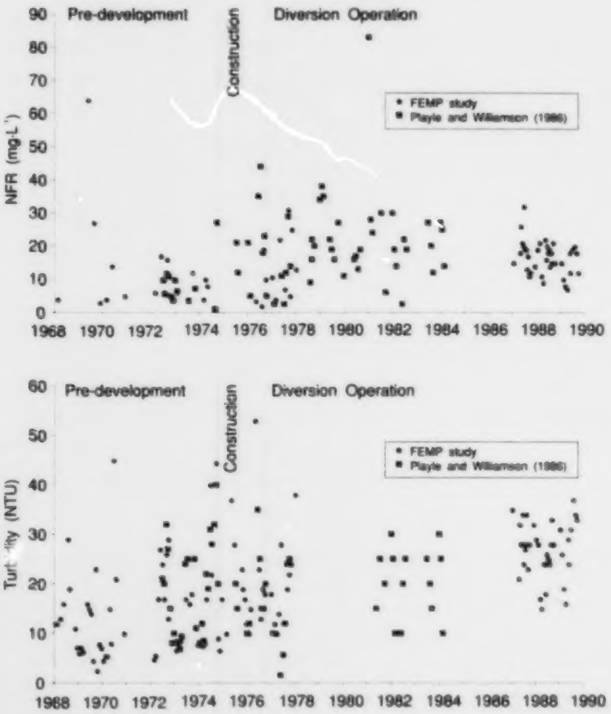
Footnotes

$^{+}$ Exceeds limit for drinking water

$^{++}$ Exceeds limit for protection of aquatic life

Exceedences in the "Max." column indicates occasional exceedences.

Figure 2.5 Turbidity and Non-Filterable Residue for Thompson, 1968 - 1989



There was a 64% increase in turbidity levels during the construction period; possible contributing factors to this increase were the damming of the less turbid Rat River flows during this period and upstream construction activity. Immediately following the construction period (and the resumption of Rat River flows), there was a 21% reduction in turbidity, to levels slightly higher than the pre-diversion levels. Turbidity levels during the 1987 - 1989 FEMP study period were approximately 94% higher than the pre-diversion levels, due to increases in turbidity in the Rat River and the contribution from documented erosion sites along the Burntwood River downstream of Threepoint Lake.

Data on non-filterable residue (NFR) are also available for the same period as the turbidity data. While these data show the same general trend over time as the turbidity data, statistical analysis of the NFR data did not show a significant increase, in contrast to the significant increase found for turbidity. One explanation for this apparent contradiction is the extreme variability in NFR compared to turbidity, particularly in the pre-development period (Fig. 2.5); the detection of a significant difference therefore requires a greater change in NFR than in turbidity. Turbidity may provide a better indication of the change in suspended sediment levels at this site because of the more extensive pre-development data record for this variable.

One interesting observation that is apparent from Fig. 2.5 is that both minimum NFR and minimum turbidity levels have increased since the diversion. Forty-two percent of the NFR measurements made before September 1976 were less than 7 mg·L^{-1}, the lowest NFR value between 1987 and 1989, while 58% of the turbidity measurements made in the pre-development period were less than 15 NTU, the lowest post-diversion turbidity level. This suggests that there has been an increased incidence of higher NFR and turbidity levels, at least at Thompson. It is not known how representative the Thompson site might be of the rest of the diversion route with respect to this apparent change since no other site has as extensive a data base; however, it may be a good indicator site because of its downstream location from some of the major erosion sites along the Burntwood River.

Future Conditions

In general, erosion to date has not been nearly as serious along the CRD as was predicted in pre-diversion studies. However, it might be overly optimistic to assume that erosion rates will necessarily diminish in the near future. As local erosional sites develop, an increasing length of bank tends to be exposed, so that volumetric rates of erosion could increase with time even if the rate of bank recession slows down. Furthermore, if gradual river bed degradation is proceeding at some points, banks that appear stable may eventually be undermined and begin to crumble. On the other hand, at some sites initial erosion slows or stops because bedrock becomes exposed as the overburden is removed.

A further severe complicating factor in projecting sediment concentrations and loads along the CRD is the fact that three further hydroelectric dams are planned for the Burntwood River, one at Wuskwatim and two further downstream. These three dams will alter water levels along most of the CRD between Notigi and First Rapids. In particular, most riverine reaches and all major rapids will be flooded and most lake levels will be increased significantly. Generally, fluvial erosion will tend to diminish as erosional sites are incorporated in reservoirs and head ponds; on the other hand, extended lengths of lake and reservoir shoreline susceptible to wind-wave erosion will be created. On balance, the net effect for most projected dams is estimated to be a further increase in sediment concentrations and loads.

Projection of future erosional rates and sediment production is subject to considerable uncertainty and could not be substantially improved without extensive field studies. Field studies would be necessary to enhance the accuracy of the analysis of the air photo interpretation, including those existing photos examined in the FEMP morphological feasibility study. In particular, field studies would be necessary to establish reference points for comparative analysis, to obtain more detailed information on shorelines (e.g. ice content) and to examine changes in channel morphology beneath the water's surface.

The participation of local residents in the establishment of the reference points as well as in the establishment of criteria for shoreline characterization would greatly enhance the accuracy and relevancy of the air photo interpretation, especially with respect to local concerns. An aerial video of the CRD, with a commentary by a local representative, would be invaluable in documenting the present and historical uses of the water bodies and their shorelines and how these uses have been affected by changes in shoreline characteristics.

The most cost efficient means of providing permanent documentation of post-diversion shoreline changes would be an ongoing program of aerial photography, flown at times of suitable lighting and river flow conditions and preferably at a 1:20,000 or larger scale. Recent developments in computer technology would enable cost-effective air photo analysis. For example, digital planimetric mapping techniques, in which shoreline locations and characteristics are stored in a computer based Geographic Information System (GIS) may allow multiple year comparisons to be undertaken relatively inexpensively. Similarly, recent developments in digital terrain mapping techniques and computer software will now allow computers to readily determine volumetric changes between two sets of topographic data, thereby computing the total volume of material eroded.

WATER QUALITY

Introduction

A three-year water quality study, from January 1987 to October 1989, of 61 physical and chemical water quality variables was conducted at 11 sites in the FEMP study area; 5 of these 11 sites were located in the Churchill River Diversion area. This section presents the results of the water quality study for the CRD area, as follows: 1) listings of those water quality variables whose values, from 1987 to 1989, exceeded the Canadian Water Quality Guidelines; 2) comparisons of current water quality conditions to historical conditions, to the extent that the data exist; 3) relationships, if any, between the water quality variables and river discharges; 4) differences in water quality conditions between the ice-free and ice-cover seasons; and 5) results of the limited bacteriological assessment of the recreational waters in and around Nelson House.

Canadian Water Quality Guidelines, established in 1987, were used as a means for assessing the water quality in the FEMP study area. Major uses of water for which Guidelines have been developed include drinking water, recreational use and the protection of aquatic life. Variations in environmental conditions across Canada will affect water quality in different ways; hence, many of the Guidelines may need to be modified according to these local conditions. The use of the Guidelines for assessing adverse effects in the FEMP study area is limited in that they have not been established for all variables, they are not based on site-specific cause and effect studies in northern Manitoba, and they do not take into account the effect of cumulative stresses caused when the values of two or more water quality variables simultaneously exceed the guideline values. They are thus a suggestive, rather than a definitive, basis for assessing adverse effects in the FEMP study area.

Natural Sites

Three of the 11 sample sites in the FEMP study area were located on unregulated rivers to provide a measure of current water quality in natural rivers in the study area and, where sufficient historical data existed, to determine the degree of natural variation in water quality between the pre- and post-development study periods. Two of the 3 natural sites were located in the Churchill River diversion area: Burntwood River above Threepoint Lake and Footprint River above Footprint Lake (Fig. 2.6).

Water quality in these two natural rivers was characterized by a number of variables which exceeded one or more of the Canadian Water Quality Guidelines for drinking water, recreational use, and protection of aquatic life. Mean levels of extractable aluminum (Al), total copper (Cu), extractable iron (Fe), turbidity and colour all exceeded the guidelines (Figs. 2.2 and 2.7). In addition, there were sporadic occasions when lead (Pb), cadmium (Cd), manganese (Mn), and zinc (Zn) exceeded the guidelines.

The natural rivers were distinguished by considerable stability in water quality between the 1972 - 1973 pre-development sampling period and the 1987 - 1989 FEMP study. There were no significant changes in the 17 variables for which comparable pre- and post-development data existed due to any cause other than a change in analytical methodology. Long-term temporal trends in metals could not be examined in the natural rivers; pre-development data on extractable or total metal species were essentially non-existent and FEMP data on dissolved metals were collected for too short a period (1 year) to enable statistical comparison.

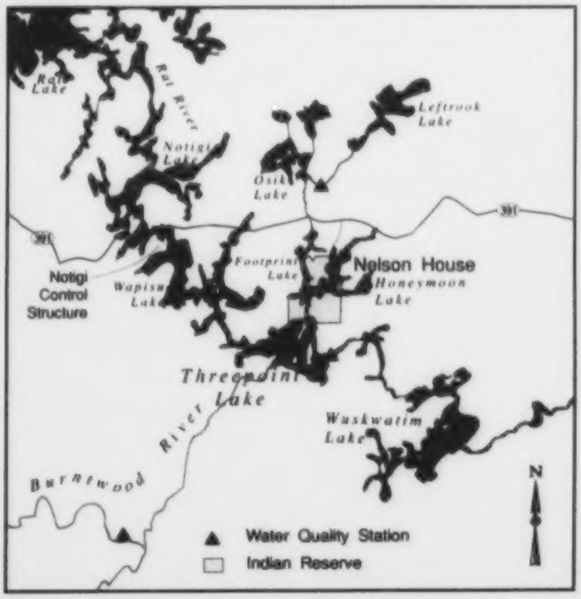


Figure 2.6 FEMP Water Quality Sites in the Churchill River Diversion Area

Figure 2.7 Water Quality Variables Which Exceeded the Canadian Guidelines along the Churchill River Diversion Route, 1987 - 1989

Var.	Type	Units	Mean	SD	Max.	Min.
Rat River above Threepoint Lake, Jan. 1987 to Sept. 1989						
Al	extractable	mg·L^{-1}	0.357[++]	0.116	0.712[++]	0.161[++]
Cd	total	mg·L^{-1}	<0.0001	0.0001	0.0004[++]	<0.0001
Cu	total	mg·L^{-1}	0.0053[++]	0.0091	0.0400[++]	0.0005
Fe	extractable	mg·L^{-1}	0.435[+,++]	0.131	0.926[+,++]	0.143
Pb	total	mg·L^{-1}	0.0008	0.0006	0.0021[++]	<0.0007
Mn	extractable	mg·L^{-1}	0.019	0.013	0.081[+]	0.004
Burntwood River above Threepoint Lake, May 1987 to March 1989						
Al	extractable	mg·L^{-1}	0.443[++]	0.148	0.700[++]	0.191[++]
Cd	total	mg·L^{-1}	0.0001	0.0002	0.0009[++]	<0.0001
Cu	total	mg·L^{-1}	0.0061[++]	0.0081	0.0296[++]	0.0012
Fe	extractable	mg·L^{-1}	0.642[+,++]	0.165	1.050[+,++]	0.183
Pb	total	mg·L^{-1}	0.0009	0.0007	0.0028[++]	<0.0007
Mn	extractable	mg·L^{-1}	0.041	0.016	0.090[+]	0.005
Footprint River above Footprint Lake, May 1987 to March 1989						
Al	extractable	mg·L^{-1}	0.190[++]	0.097	0.410[++]	<0.100
Cu	total	mg·L^{-1}	0.0232[++]	0.1060	0.5530[++]	0.0005
Fe	extractable	mg·L^{-1}	0.420[+,++]	0.246	1.150[+,++]	0.091
Pb	total	mg·L^{-1}	0.0011	0.0030	0.0161[++]	<0.0007
Mn	extractable	mg·L^{-1}	0.057[+]	0.078	0.296	<0.002
Zn	total	mg·L^{-1}	0.0040	0.0099	0.0515[++]	0.0004
Burntwood River at the outlet to Threepoint Lake, Sept 1986 to Oct. 1989						
Al	extractable	mg·L^{-1}	0.377[++]	0.209	1.360[++]	<0.100
Cd	total	mg·L^{-1}	0.0001	0.0001	0.0006[++]	<0.0001
Cu	total	mg·L^{-1}	0.0044[++]	0.0059	0.0264[++]	0.0005
Fe	extractable	mg·L^{-1}	0.477[+,++]	0.303	2.010[+,++]	0.135
Pb	total	mg·L^{-1}	0.0008	0.0009	0.0046[++]	<0.0007
Mn	extractable	mg·L^{-1}	0.020	0.028	0.179[+]	0.006
Burntwood River at Thompson, Jan. 1987 to Oct. 1989						
Al	extractable	mg·L^{-1}	0.491[++]	0.154	0.826[++]	0.230[++]
Cu	total	mg·L^{-1}	0.0040[++]	0.0051	0.0240[++]	0.0009
Fe	extractable	mg·L^{-1}	0.624[+,++]	0.189	0.931[+,++]	0.256
Pb	total	mg·L^{-1}	0.0009	0.0006	0.0027[++]	<0.0007

Footnotes

[+] Exceeds limit for drinking water

[++] Exceeds limit for protection of aquatic life

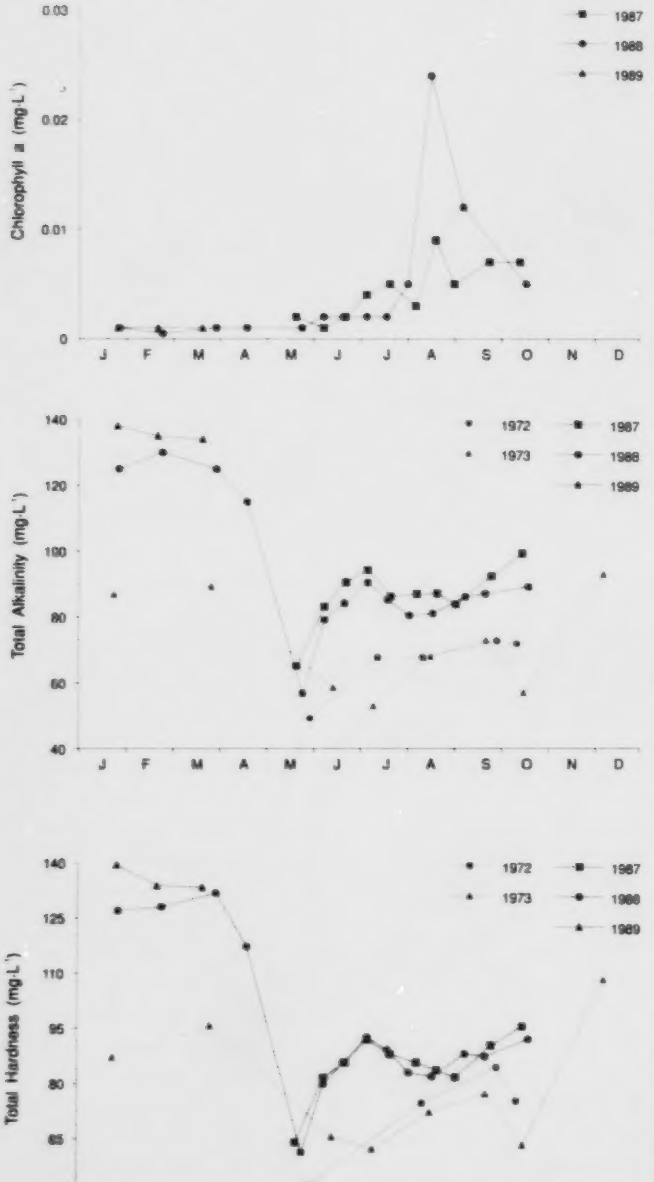
Exceedences in the "Max." column indicates occasional exceedences.

Water quality - discharge relationships for sites on the natural Burntwood and Footprint rivers were examined only for the FEMP study period, since there were no pre-development discharge data. General characteristics of the discharge relationships in the natural rivers included: 1) relatively large numbers of discharge correlated variables (the natural Burntwood River site had more variables correlated with discharge than at any of the other FEMP sites); 2) the dominance of negative slopes (e.g. conductivity, alkalinity, hardness, some major ions, etc. at the natural Footprint River site); and 3) the frequent occurrence of strong correlations (i.e. r^2 greater than 0.4).

At the natural Burntwood River site there were few differences in water quality between the ice-free and the ice-cover seasons. Concentrations of dissolved manganese (Mg), sodium (Na), and zinc (Zn) were higher under ice cover than during the open-water season, while colour and chlorophyll a were lower (the latter probably due to the imposition of light limitation on algae growth by accumulated snow cover). Before development there was more variation in these parameters, making any seasonal differences during this period less distinct.

At the natural Footprint River site, there were clear differences in the values for many variables between the ice-free and ice-cover seasons during the 1987-1989 FEMP sampling period (Fig. 2.8). Most variables were higher under ice cover (e.g. conductivity, alkalinity, hardness, most major ions, dissolved iron (Fe), etc.), while dissolved copper (Cu) and chlorophyll a were lower. A possible explanation for the higher levels of some variables under ice is their negative correlations with river discharge and the low flows which occurred on the river in winter. A qualitative examination of the limited pre-development database showed the same general pattern was present prior to development for those variables sampled in both the pre- and post-development periods.

Figure 2.8 Seasonal Water Quality Trends for Selected Water Quality Variables in the Footprint River above Footprint Lake



Threepoint Lake and Nelson House Area

Two FEMP sample sites were located on regulated water bodies in this area: Rat River above Threepoint Lake and Burntwood River at the outlet of Threepoint Lake (Fig. 2.6). Water quality conditions at the Rat River site, during the FEMP 1987-1989 sampling period, were generally similar to those on the natural rivers: mean levels of extractable Al, extractable Fe, total Cu, and turbidity (and colour on the Burntwood River site) all exceeded Canadian Water Quality Guidelines, with sporadic occasions when Cd, Pb and Mn levels exceeded the guidelines (Figs. 2.2 and 2.7). Water quality conditions, during 1987 - 1989, for the Burntwood River at the outlet of Threepoint Lake were similar to those observed in the 3 rivers that flow into Threepoint Lake, namely: mean levels of extractable Al, extractable Fe, total Cu, and turbidity all exceeded Canadian Water Quality Guidelines, while there were sporadic occasions when Cd, Pb, and Mn levels exceeded the guidelines.

In addition to the 3-fold increase in turbidity at the Rat River above Threepoint Lake site, there were many other significant changes from the 1972 - 1973 pre-development sampling period to the FEMP study period (Fig. 2.9). Annual mean conductivity, alkalinity, hardness, total organic carbon (TOC), orthophosphate (PO_4), calcium (Ca) and reactive silicon (Si) decreased by 15 to 60%, while sodium (Na), potassium (K), chloride (Cl) and fluoride (F) increased by 10 - 80%. All of these changes are directly attributable to the diversion and are a reflection of differences in water quality between the Churchill River and the pre-existing Rat River. In most cases, the changes were no greater than the difference between the Rat and Churchill rivers.

There were two particularly interesting findings. The first was the greater decrease in TOC than what might have been expected; the flooded vegetation and organic soils in SIL and Notigi Reservoir might be expected to contribute organic carbon (C) to the water column. This issue will be examined more extensively by DFO. The second finding was the fact that total phosphorus (P) concentrations in the Rat River were not lower during the FEMP study than prior to diversion despite lower concentrations in the Churchill River. This finding suggests phosphorus continues to be

Figure 2.9 Comparison of Water Quality in the Rat River before (1972 - 1973) and after (1987 - 1989) Churchill River Diversion with Water Quality in the Churchill River near Leaf Rapids (1972 - 1973)

	Rat River		**Churchill River**
	Pre- Diversion	Post- Diversion	
pH (units)	7.9	7.66	7.6
Conductivity ($\mu S \cdot cm^{-1}$)	120	102	91
Turbidity (NTU)	5	17	5
Alkalinity (Total)	56.4	46.4	40.4
Hardness (Total)	61.2	45.9	41.9
TOC	10.7	6.38	8.7
NO_2NO_3	0.237	0.019	0.157
Ortho PO_4	0.005	0.002	0.003
Total P	0.023	0.026	0.017
Dissolved Na	2.2	2.7	3.0
Dissolved K	0.9	1.02	1.2
Dissolved Ca	18.2	12.3	12.5
Dissolved Cl	1.0	1.1	1.2
Dissolved F	0.005	0.09	0.08
Dissolved SO_4	2.7	2.5	3.6
Reactive Si	3.6	1.83	2.6
Dissolved Fe	0.07	0.096	0.05
Dissolved Mn	<0.01	0.003	<0.01
Dissolved Cu	0.002	0.0010	0.002
Dissolved Pb	<0.001	0.0007	<0.001
Dissolved Zn	0.007	0.0014	0.002

released from flooded terrain as late as 13 years after impoundment and diversion.

Impacts of diversion on water quality in the Burntwood River at the outlet of Threepoint Lake could not be quantified due to the lack of pre-development data for this site. Significant changes would be expected and should be qualitatively similar to those in the Rat River.

Positive correlations dominated the significant relationships between water quality and discharge, for the FEMP study period, for both the Rat River above Threepoint Lake and the Burntwood River at the outlet of Threepoint Lake. The dominance of positive correlations at these sites was the reverse of the situation in the natural rivers and in the Burntwood River at Thompson prior to diversion, where negative correlations dominated. This is evidence of the increased importance of eroded shoreline materials in regulating water quality. Whereas water quality typically was highest during periods of peak flow prior to diversion, water quality now decreases with increasing river flows. All of these correlations, however, were too weak to be of much use for impact prediction or management (i.e. r^2 less than 0.25).

Few variables displayed distinct differences between the ice-cover and ice-free seasons during the FEMP study. At the Rat River site, total dissolved nitrogen (TDN), total nitrogen (N) and dissolved NO_2-NO_3 occurred in higher concentrations under ice, while chlorophyll a concentrations were higher in the ice-free season (Fig. 2.10). This buildup of dissolved N constituents was likely due to lower dissolved N demand because of reduced algal growth rates under ice-cover. Higher TDN and dissolved NO_2-NO_3 concentrations under ice-cover were also observed at the Burntwood River site, probably due to the same cause as in the Rat River (Fig. 2.11). Much higher dissolved zinc (Zn) concentrations under ice-cover were also observed at this site. Higher dissolved Zn concentrations occurred under ice-cover in all three major inflows to Threepoint Lake as well, although the seasonality was not as distinct as at the outlet. Lack of data prevented a quantitative analysis of seasonal patterns in dissolved Zn in the pre-development period.

Bacteriological Assessment

A bacteriological assessment of the recreational water in the Nelson House area was conducted in 1987, consisting of a seasonal study from May to September at 8 sites and an intensive study in the vicinity of the sewage treatment plant outfall in August. Geometric mean fecal coliform bacteria counts for the seasonal study generally ranged between 1 and 6 bacteria per 100 millilitres (mL). The geometric mean for the intensive study was 38 per 100 mL; a few high coliform counts were recorded, but they were transient. Comparison of the results of the intensive study to the Canadian Water Quality Guidelines of 200 bacteria per 100 mL indicates that the bacteriological water quality at this site was generally acceptable for recreational water uses. Limited sampling frequency for the seasonal study precludes direct comparison of its results to this guideline.

Burntwood River at Thompson

Water quality in the Burntwood River near Thompson had similar characteristics to the other sites in the local (Burntwood, Footprint, and Aiken rivers) and Churchill River drainages. Levels of most parameters were well

Figure 2.10 ***Seasonal Water Quality Trends for Selected Water Quality Variables in the Rat River above Threepoint Lake***

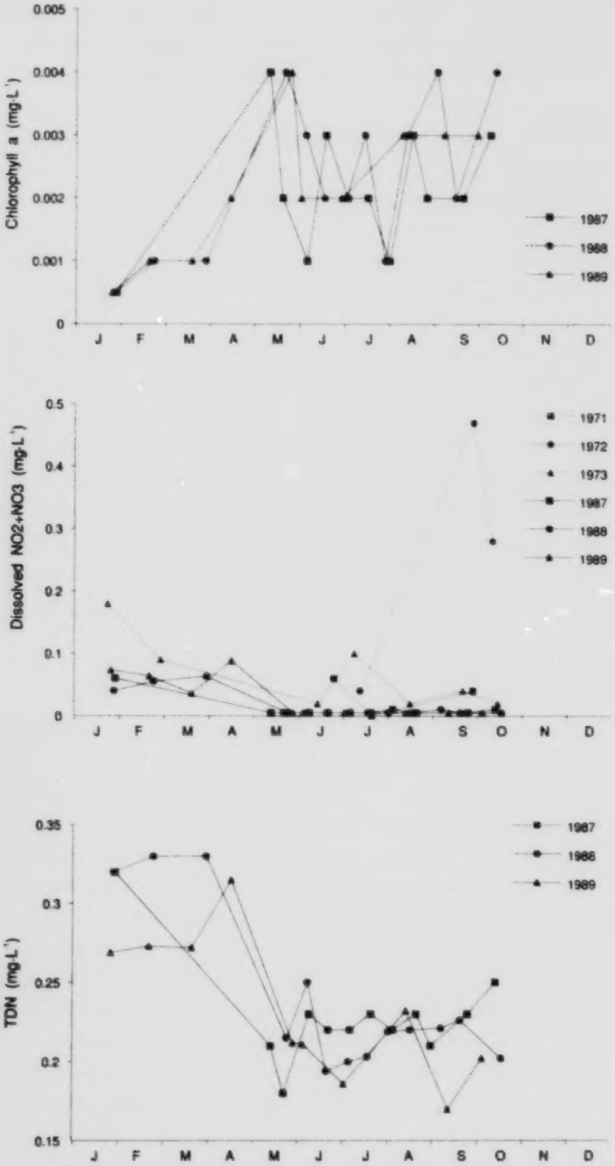
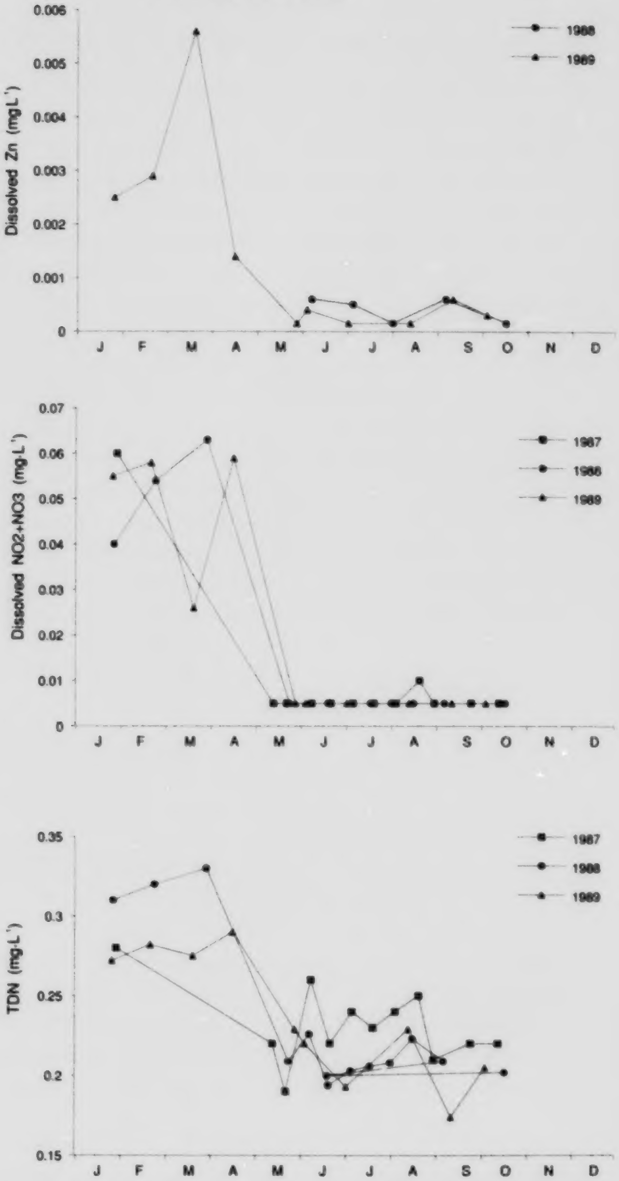


Figure 2.11 ***Seasonal Water Quality Trends for Selected Water Quality Variables in the Burntwood River at the Outlet of Threepoint Lake***



within Canadian Water Quality Guidelines, and those which exceeded the Guidelines were the same as in the local drainages. Mean values for turbidity, colour, extractable Al, total Cu, and extractable Fe all exceeded Canadian Water Quality Guidelines, and there were sporadic occasions when Pb exceeded the guidelines (Figs. 2.4 and 2.7).

The Burntwood River at Thompson is the only site in the FEMP study area which was sampled before, during, and immediately after construction of a hydro project, as well as during FEMP; it also has the most extensive baseline data record, with sampling conducted continuously from 1967 to 1974. However, only 10 variables were common to all 4 periods, thus seriously limiting the nature of the water quality changes which can be conclusively stated.

Most of the changes in water quality did not occur until after the autumn of 1977, when the diversion was fully operational. Significant water quality changes that occurred between the pre-development (1967 - 1974) period and the FEMP (1987 - 1989) period included decreases in conductivity, alkalinity, hardness, reactive Si, dissolved Ca, and dissolved Fe, and an approximate doubling of turbidity (Fig. 2.12). Several variables were not routinely measured until the construction period, 1974 - 1976; among these significant reductions occurred in dissolved Mg and in extractable Al between 1974 - 1976 and 1987 - 1989. All of these decreases were due to the introduction of softer Churchill River water (Fig. 2.9).

There were several changes in water quality that were evident during the construction period, when Rat River flows were cut off at the outlet of Notigi Lake or during the immediate post-diversion period (1976 - 1977), as flows were gradually increased. For example, hardness increased during the construction period, due to reduced flows on the Burntwood River, returned to the pre-development level in the immediate post-diversion period, and further declined after 1978. Another example was the approximate doubling of total phosphorus (P) concentrations between the construction and immediate post-impoundment periods, probably due to the release of P from flooded organic soils and vegetation. The total P concentrations in 1987 - 1989 were not significantly different from the levels prior to diversion (1967 - 1974); however, the P flux may still be occurring, as indicated by higher total P concentrations in the Rat and Burntwood rivers than in the Churchill River. The end point of this process is not the pre-development concentration for the site, but the level in the source of the flow, the Churchill River.

Most correlations between water quality and discharge during the pre-development period and all significant correlations during the construction and immediate post-construction periods were negative; however, all significant correlations with discharge during the FEMP study were positive at this site. Although more variables were correlated with discharge during the FEMP study, the relationships generally were much weaker than in the preceding periods and thus do not offer much promise for impact prediction or management. It is interesting to note that turbidity was positively correlated with discharge in the pre-development period, was not correlated with discharge in the construction and immediate post-diversion periods, and then was again positively correlated with discharge in the FEMP study period. The occurrence of positive correlations with discharge for turbidity and NFR in the Burntwood River at Thompson but not upstream at the outlet of Threepoint Lake is indicative of shoreline erosion occurring between these points. The discharge relationships for turbidity and NFR are strong enough to offer some promise of predictive value.

Figure 2.12 Means and Standard Deviations for Ten Water Quality Variables at Thompson, 1967 - 1989

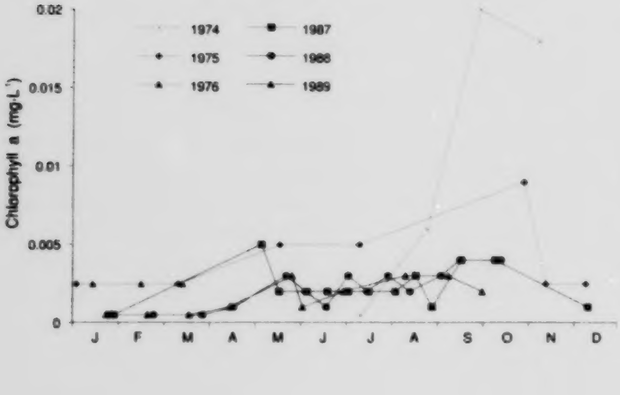
	Conductivity (lab)		Turbidity (lab)		Alkalinity (total)		Diss Fe		Reactive Si	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Pre	141.0[1]	7	14.0[1]	2	65.0[1]	3	0.138	0.027	3.94[1]	0.25
Const	148.0	6	23.0	1	70.0[1]	4	0.150	id.	4.10	0.76
Post	125.0	25	18.0	<1	60.0[1]	2	id.		3.25[1]	0.50
Current	115.0	2	27.0[1]	2	53.0[1]	1	0.077	0.010	2.01	0.12

	Diss Ca		Hardness (total)		Diss Mg		Extr Al		Total P	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Pre	21.3	2.7	69.0[1]	3	id.		id.		0.028	0.009
Const	21.5	0.8	77.0[1]	4	6.5[1]	0.1	0.870	0.207	0.039	0.010
Post	id.		66.0[1]	<1	id.		0.545	0.021	0.065	0.007
Current	14.6	0.1	53.0	<1	4.0	0.1	0.488	0.095	0.036[1]	0.003

Pre = 1967 to May 1974
Const = June 1974 to August 1976
Post = September 1976 to December 1977
Current = January 1987 to October 1989
id. = insufficient data
[1] = discharge - standardized variables

As was the case at many other sites, chlorophyll a concentrations were generally lower under ice cover than during the ice-free season (Fig. 2.13); this probably reflects the reduced light penetration through the snow and ice. The extensive data base for the Burntwood River at Thompson site, including the routine measurements under ice cover in the pre-development and construction periods, enabled the most complete analysis for seasonal trends of any of the FEMP water quality sites. Only chlorophyll a showed a marked seasonality in either of these two periods.

Figure 2.13 Seasonal Trends in Chlorophyll a Concentrations in the Burntwood River at Thompson



MERCURY

Introduction

Mercury in the FEMP study area first became an issue in the late 1970s with the discovery of elevated mercury levels in fish along the CRD route. A federal-provincial study, The Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA), concluded that extensive flooding of organic material led to the increased net production of methyl mercury by bacterial processes and a subsequent increase in methyl mercury levels in fish. It was estimated that it would take decades before there would be a return to pre-development mercury levels. Recommendations were made for an ongoing fish monitoring program, for the implementation of fish management activities as a means of mitigating the mercury problem, and for the explicit consideration of elevated mercury levels in fish following impoundment in the planning and costing of reservoirs.

The mercury problem was not a predicted impact of the CRD, yet it is among the most severe of the impacts which have been documented and a continuing source of concern for the native residents within the FEMP study area. Because of the importance and expected longevity of this problem, continued investigation of mercury became a FEMP priority. In particular, the goals of the FEMP mercury program were: 1) to better define the expected duration of the mercury problem; 2) to provide a better understanding of the factors affecting the net production of methyl mercury to determine if it could be regulated; and 3) to monitor mercury levels in fish in Southern Indian Lake (SIL) and Issett Lake to identify any recent temporal trends. (Mercury levels in fish in other major lakes in the FEMP study area were monitored by the Manitoba Department of Natural Resources.)

To better define the expected duration of the mercury problem, measurements of net mercury methylation rates were made at a number of reservoirs of different ages: 1) Laurie Reservoir (flooded in the early 1950s); 2) Notigi Reservoir (flooded in 1976); 3) Sipiwesk Lake (flooded in the early 1960s); 4) Stephens Lake (flooded in the early 1970s); and 5) Sokatisewin Lake, Saskatchewan (Island Falls Reservoir, flooded in 1929). In addition, yearly measurements of net mercury methylation rates were made, from 1986 to 1989, at two locations; Methyl Bay, a small isolated bay of SIL and Granville Lake, a riverine lake on the Churchill River immediately upstream of SIL which has not been affected by the flooding. For all locations, 5 surveys were taken, at approximately 2 week intervals, from 3 or 4 near shore and offshore sites.

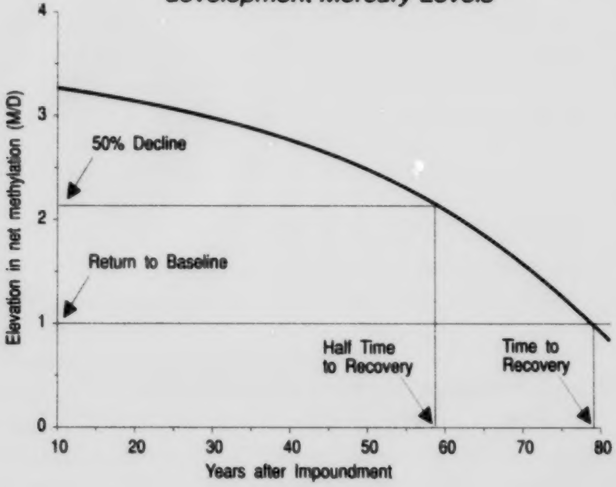
To determine if the process of net mercury methylation could be regulated, studies were conducted to identify the groups of bacteria responsible for mercury methylation and mercury demethylation. Identifications were made on the basis of experiments with specific metabolic inhibitors.

To identify recent temporal trends in mercury levels in fish, mercury levels in six species from 5 regions of SIL and from Issett Lake were measured. This mercury data extended the historical record for whitefish, which began in 1975, and for walleye and northern pike, which began in 1978 or 1979, depending on the site.

Duration of Elevated Mercury Levels

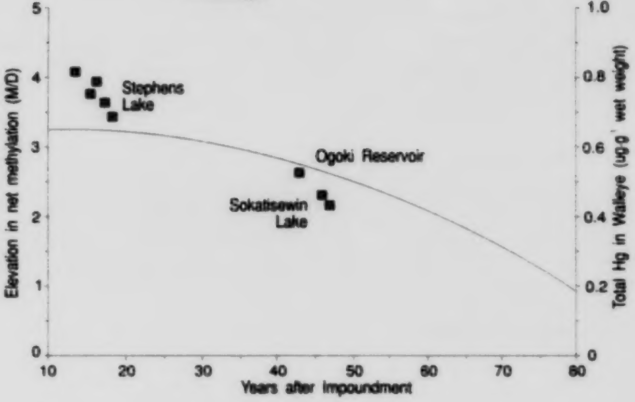
A model to predict the estimated time for a return to pre-development mercury levels was developed on the basis of the measured net rates of methyl mercury production in reservoirs of various ages (Fig. 2.14). (Because there are no pre-development data on net rates of methyl mercury production for any reservoir in northern Manitoba, Granville Lake data were used as a surrogate for pre-development conditions.) This model indicates there will be a slowly accelerating rate of decline in net methyl mercury production over time. The half time (i.e. the period required for a 50% reduction) is estimated to be 59 years, with an estimated return to pre-development levels 78 years after impoundment.

Figure 2.14 Estimated Time for a Return to Pre-development Mercury Levels



The validity of this model was evaluated by overlaying pike and walleye mercury data from selected reservoirs on the predicted decline curve. All fish mercury data were from reservoirs with the following similar characteristics: 1) similar extent of flooding; 2) location within the boreal forest zone; 3) the same major fish species; 4) comparable regional or pre-development baseline mercury levels; and 5) the absence of an upstream reservoir within 130 km. The only Canadian reservoirs which appeared to satisfy these requirements were Stephens and Sokatisewin lakes, and the Ogoki reservoir in northwestern Ontario (flooded in 1943). As seen in Fig. 2.15, there is good agreement between the predicted net methyl mercury production and the measured mercury concentrations in fish.

Figure 2.15 Relationship between Elevation in Methylation Balance (M/D) and Mean Mercury Concentration in Walleye



The single most important factor affecting net methyl mercury production, and thus ultimately the duration of the mercury problem, is the amount and type of flooded organic material. This conclusion of the CMMA was reinforced by the FEMP mercury program, as evidenced, for example, by the results of the sampling program in Methyl Bay, SIL, in 1986. Although higher, on average, than at the offshore station at Methyl Bay or the Granville Lake stations, considerable variation in methylation activity was evident among the 3 near shore (flooded) stations (Fig. 2.16). An examination of the site characteristics revealed the following differences: 1) repeated sampling at station #1, since 1982, had effectively removed the organic layer; 2) oxygen and nitrogen concentrations at station #2 were the most similar to those encountered at flooded sites in previous years; and 3) organic carbon concentrations at station #3, a new station, were very low. Thus, the variation in methylation activity at these stations appeared to be the result of the substantial differences in sediment organic content among the sites.

Further evidence of the importance of the amount of organic material was provided by the higher than expected methylation activity in Sipiwesk Lake in 1987 in comparison to the predictions of the mercury duration model. It is postulated that the reason for this apparent contradiction of the model is the manner in which this reservoir is regulated. Since the operation of the Jenpeg dam in 1976, Sipiwesk Lake levels have been generally low in summer and high in winter, the reverse situation of most hydroelectric reservoirs in Canada. One of the results of this regime is exposure of the drawdown zone

Figure 2.16 Methylation, Demethylation, and Methylation/Demethylation Rates for Methyl Bay, SIL and Granville Lake, July 2 - September 3, 1986

Station No.[1]	Total Carbon	Organic Carbon	M	D	M/D
	mg (g dry sediment)$^{-1}$		% added Hg, g^{-1}h^{-1}		
Methyl Bay					
1	108[2]	103[2]	0.0028	0.0898	0.0312
2	191	187	0.0124	0.1616	0.0769
3	46	40	0.0003	0.0627	0.0042
4	22	21	0.0002	0.0146	0.0161
Granville Lake					
9	32	30	0.0006	0.0259	0.0224
10	30	29	0.0008	0.0302	0.0257
11	35	34	0.0010	0.0358	0.0289
12	23	22	0.0006	0.0127	0.0474

[1] Station numbers 1, 2, 3 are flooded near shore; 9, 10, 11 are reference near shore; and 4 and 12 are reference offshore

[2] Includes 1 estimated value in the average. All values are time-weight means.

in summer when it can become recolonized by grasses and other fast growing vegetation. These materials are flushed into the lake during periods of high water, providing a continuous source of fresh organic matter. Thus, it is clear that the model's prediction of a decline in mercury is based on a decline over time of the availability of organic matter.

The type, as well as the amount, of flooded organic matter will also determine its availability over time, as was evidenced by the mercury problem in Cedar Lake, Manitoba. Mercury concentrations in pike and walleye in Cedar Lake declined 12 to 14 years after its impoundment by the Grand Rapids Generating Station to levels commonly found in northern Manitoba lakes remote from hydro development. The type of vegetation flooded here, predominately marsh macrophytes and sedges, decomposed more quickly than the boreal forest vegetation flooded in the reservoirs in the FEMP study area and contributed much less (estimated 90%) organic matter per unit area of flooded land.

Another factor which may affect the duration of the mercury problem is sediment deposition. There is some suggestion that this may have happened in Rat Lake. A small but significant decline in mercury in northern pike in Rat Lake between 1986 and 1989 was observed coincident with an apparent increase in shoreline erosion in Notigi Reservoir. The covering of organic matter with inorganic sediment may be effectively preventing the stimulation of microbial methylation; the long-term impact of eroding clays on the duration of the mercury problem in the CRD is unclear and remains to be established.

The downstream transport of mercury in water has been suggested as a possible factor in determining both the magnitude and duration of elevated mercury levels in fish. Recent improvements in methodologies enabled the direct measurement of total mercury and methyl mercury in water as part of the FEMP mercury program. (See volume 1, chapter 4.) Methyl mercury levels in water sampled at Thompson were in the same range as that sampled in Granville Lake, suggesting that methyl mercury produced in Notigi Reservoir does not travel as far as Thompson, 130 km downstream. Thus, it would appear that locations 130 km or more downstream of a reservoir in the FEMP study area would not have elevated mercury levels in water due to elevated rates of methyl mercury production in the reservoir.

Mitigation

The potential for regulating the net production of methyl mercury was investigated; regulation of this process would provide an effective mitigative measure for elevated mercury levels in fish. Based on the results of a 1987 FEMP pilot study, and of investigations elsewhere, two groups of bacteria, methanogens and sulphate reducers, were identified as the most likely important bacteria in the net production of methyl mercury. The importance of each group was subsequently determined by measuring the reduction in the specific methylation and demethylation rates caused by the addition of a specific inhibitor for each group.

It was found that the methanogens and sulphate reducers jointly accounted for the majority of seasonal mean methylation (66%) and demethylation (50%) in Granville Lake sediments (Fig. 2.17). The two groups were equal contributors to both processes. Conditions in the flooded zone of Methyl Bay appear to be particularly attractive to those groups, where they jointly accounted for all of the methylation and demethylation. A group may have dominated one of the processes, but not the other, at a particular time and place, but both groups made equal contributions over the season on average.

Figure 2.17 ***Comparison of Seasonal Mean Specific Rates of Microbial Methylation and Demethylation Attributable to Methanogenic and Sulphate Reducing Bacteria, July 4 - August 24, 1988***

% added Hg, $g^{-1} \cdot h^{-1}$

	Methylation			**Demethylation**		
Site	*Total*	*Methanogen*	*Sulphate Reducers*	*Total*	*Methanogen*	*Sulphate Reducers*
Methyl Bay, South Indian Lake						
1	0.0034	0.0015	0.0029	0.2620	0.0939	0.1404
2	0.0054	0.0026	0.0033	0.3313	0.1862	0.2034
3	0.0042	0.0003	0.0023	0.1004	0.0127	0.0409
Mean	0.0043	0.0015	0.0028	0.2279	0.0976	0.1282
Granville Lake						
5	0.0010	0.0000	0.0006	0.0861	0.0137	0.0175
6	0.0009	0.0008	0.0001	0.0438	0.0140	0.0034
7	0.0007	0.0001	0.0002	0.0523	0.0221	0.0190
Mean	0.0009	0.0003	0.0003	0.0581	0.0166	0.0133

All values are time-weighted means

The finding that the same bacterial groups are responsible for both methylation and demethylation indicates that it may be difficult to develop mitigative measures based on the selective inhibition of the methylators or stimulation of the demethylators. Other approaches, beyond the scope of FEMP, will have to be considered, such as an investigation of the factors regulating the transmission of the gene responsible for producing the demethylation enzyme within the bacterial community.

Microbial mercury methylation and demethylation rates were measured in sediments from a number of lakes and reservoirs representing a range of physical and chemical conditions to determine the most important factors in regulating net methyl mercury production. The primary limiting factor of methylation is organic matter availability, which influences methylation rates by regulating bacterial activity and by promoting development of the anoxic conditions which are favoured by the methanogenic and sulphate reducing bacteria. Methylation in sediments of lakes and reservoirs in the FEMP area is not limited by inorganic mercury availability.

The factor(s) that regulate microbial demethylation rates are less well understood, although organic matter and total microbial activity appear to be the most important. Demethylation rates were positively correlated with both sediment organic content and total microbial activity. Sediment pH, total mercury concentration, and oxygen availability had no significant influence on demethylation rates. This third factor may provide a partial explanation for the differential stimulation of methylation over demethylation in flooded sediments although additional study on the role of sediment oxygen conditions in regulating demethylation is required.

It is currently not possible to mitigate the mercury problem through the regulation of the methylation and demethylation processes, either directly through the regulation of the methylating and demethylating bacteria or indirectly through the alteration of environmental conditions. Other alterations of environmental conditions, such as liming, selenium additions, and sediment resuspension, are similarly inappropriate as mitigation measures in the FEMP study area. Liming, a proposed solution to mercury problems related to lake acidification, would be ineffective in the FEMP study area reservoirs because the mercury problem here was not caused by a pH reduction. Selenium additions, while a demonstrated effective measure in reducing mercury bioaccumulation in aquatic food webs, must be made at concentrations ($1\text{-}5 \mu g \cdot L^{-1}$) that come uncomfortably close to the Canadian limit for drinking water ($10 \mu g \cdot L^{-1}$). Sediment resuspension as a remedial measure was tested under the CMMA; results showed that increased suspended sediment concentrations did not significantly reduce mercury concentrations in fish and caused slight increases in some cases. Indeed, the mercury problem developed at most locations in spite of increased suspended sediment concentrations.

Increasing fish growth has been suggested as a way of mitigating mercury problems; this suggestion is based on the hypothesis that if fish growth can be increased without causing a proportionate increase in methyl mercury availability, then the mercury concentration in fish would be reduced. Increased fish growth could be encouraged by intensive fishing and/or nutrient addition. However, neither of these methods may be effective in the FEMP study area. Intensive fishing is subject to some practical limitations, such as: 1) the need to have small enough lakes to make it feasible to significantly reduce fish standing stocks; 2) the potential for immigration of contaminated fish from other parts of the system must be limited; and 3) any trophy sport-fishing on a lake would be lost. These restrictions would limit the use of intensive fishing on most of the lakes in the CRD. Nutrient addition experiments were tried under the CMMA; while primary productivity increased, no effect on fish growth was noted. Furthermore, primary productivity in the turbid lakes of the CRD is generally light limited, so nutrient additions will not have a significant impact on primary productivity or fish growth.

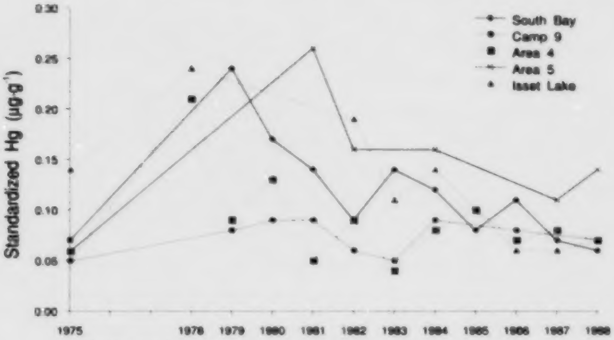
Thus, the only effective mercury mitigation measure continues to be the selective harvesting of fish with lower mercury levels, as suggested under the CMMA. This measure is based on the knowledge that some fish species such as whitefish and smaller-sized fish in a given species will have lower mercury concentration than predatory or larger-sized fish. The potential negative impact on future spawning stocks and the socioeconomic impact of selective harvesting on the resource users, especially the native communities in the FEMP study area, must be considered in the implementation of this measure.

Mercury Levels in Fish

SIL and Issett Lake have the longest data record for mercury levels in fish in reservoirs in the world. These records were extended by FEMP studies conducted in 1987 and 1988 in 4 regions of SIL, South Bay (Area 6), Camp 9 (Area 2), Area 4, and Area 5, as well as in Issett Lake. The objective of these studies was to examine trends and site-to-site differences that occurred in mercury concentrations in fish after more than 10 years since impoundment.

For most sites, mean muscle mercury concentrations in whitefish peaked in the late 1970s and have declined steadily to near 1975 values (Fig. 2.18). Area 5 whitefish, however, had mercury concentrations in 1988, 12 years after impoundment, which were double the concentrations in fish before impoundment. These Area 5 whitefish were slightly higher in mercury than those from Issett Lake, where water levels rose by more than 7 m causing more extensive flooding than in SIL.

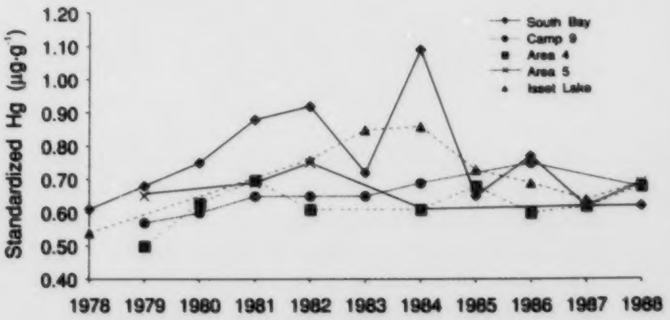
Figure 2.18 Standardized Mean Muscle Mercury Concentrations for Whitefish in Southern Indian and Issett Lakes, 1975 - 1988



Standardized data: 350 mm fork length

Mean muscle mercury concentrations for pike, at all sites, rose significantly immediately after flooding (Fig. 2.19). Mean values varied among sites and years but most means have been in the range of 0.5-1.0 $\mu g \cdot g^{-1}$ over the period 1980-1988. Highest values in 1988 and 1987 were in pike from Issett Lake; pike from Area 5 and South Bay were slightly lower in mercury than those from Issett Lake.

Figure 2.19 Standardized Mean Muscle Mercury Concentrations for Northern Pike in Southern Indian and Issett Lakes, 1978 - 1988

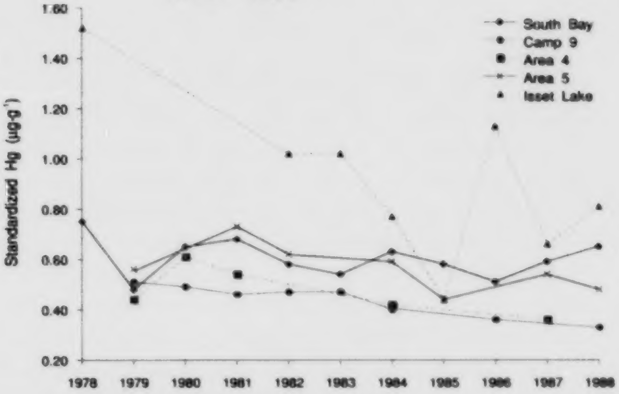


Standardized data: 550 mm fork length

There was no indication of declining mercury concentrations in pike 12 years after impoundment of SIL.

Mean muscle mercury concentrations for walleye were, in general, much higher than lake whitefish and usually slightly lower than pike (Fig. 2.20). Means rose immediately after flooding, reaching values of $0.49 \mu g \cdot g^{-1}$ to $0.73 \mu g \cdot g^{-1}$ at most sites in SIL. In Issett Lake, the highest mean mercury concentration in walleye was recorded in 1978 at a value of $1.52 \mu g \cdot g^{-1}$. Mercury levels in walleye appear to have declined at some sites, but not others; however, year-to-year variability of means remains high, especially for fish from Issett Lake.

Figure 2.20 ***Standardized Mean Muscle Mercury Concentrations for Walleye in Southern Indian and Issett Lakes, 1978 - 1988***



Standardized data: 400 mm fork length

The FEMP sampling results reaffirmed the conclusion of the CMMA that mercury concentrations in fish varied according to species, length of time since flooding, and location. Particularly notable was the large variation in mercury concentrations found even 12 years after flooding (Fig. 2.21). The year-to-year variability in mercury levels may be attributable, at least in part, to variability in the size distribution of fish in each year's sample. Means which were standardized or adjusted for length were not as variable year-to-year as arithmetic means, illustrating the effect of size on mercury concentration.

Three sites, Issett Lake, Area 5, and South Bay have been consistently higher in fish mercury concentrations than other sites in SIL. Issett Lake and area 5 of SIL were both extensively flooded; this similarity helps explain the similarity in fish mercury concentrations. It is more difficult to explain the occurrence of high mercury levels in South Bay. It may be that local conditions in South Bay have facilitated higher methylation activity here (e.g. through the introduction of organic material from the high erosion rates in South Bay) or that fish high in mercury are moving into South Bay from Issett Lake through the diversion channel.

Figure 2.21 ***Ranges of Muscle Mercury Concentrations in Southern Indian and Issett Lakes, 1987 and 1988***

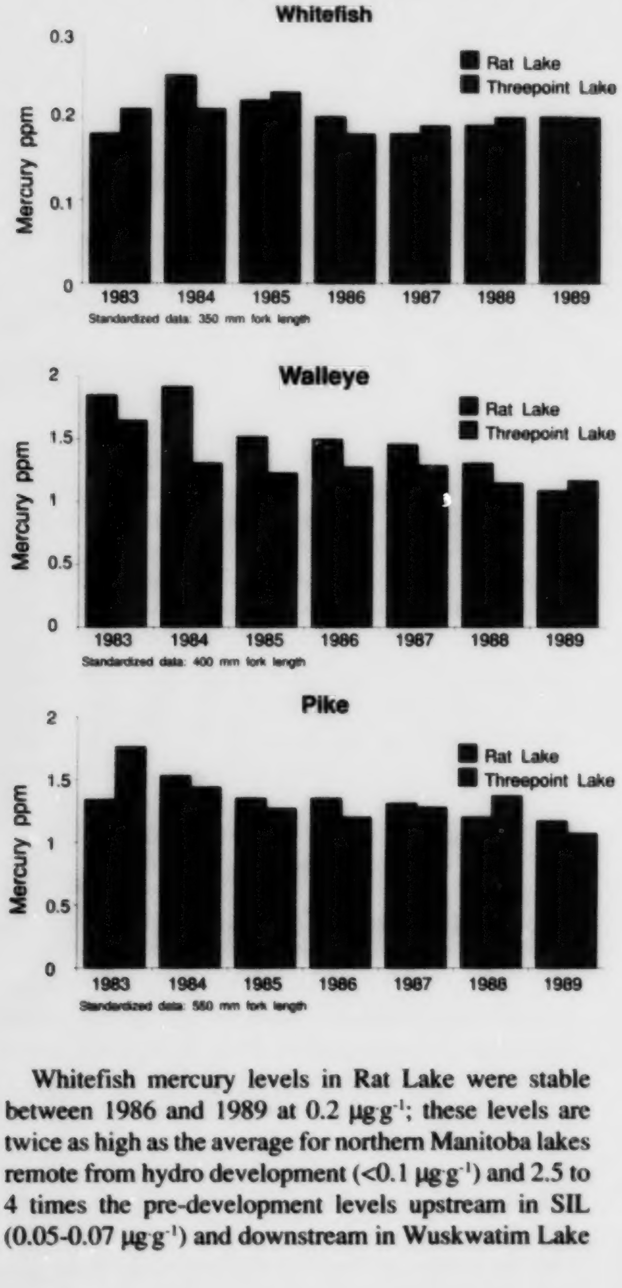
Site	*Year*	*Muscle[Hg] Range ($\mu g \cdot g^{-1}$)*
Whitefish		
South Bay	1987	0.01 - 0.36
	1988	0.01 - 0.22
Camp 9	1988	0.01 - 0.34
Area 4	1987	0.03 - 0.24
	1988	0.04 - 0.14
Area 5	1987	0.06 - 0.55
	1988	0.08 - 0.39
Issett Lake	1987	0.02 - 0.52
	1988	0.02 - 0.52
Pike		
South Bay	1987	0.08 - 1.27
	1988	0.33 - 1.35
Camp 9	1988	0.29 - 1.14
Area 4	1987	0.25 - 0.99
	1988	0.37 - 1.04
Area 5	1987	0.36 - 0.99
	1988	0.45 - 1.93
Issett Lake	1987	0.28 - 1.84
	1988	0.15 - 2.67
Walleye		
South Bay	1987	0.38 - 1.28
	1988	0.27 - 2.88
Camp 9	1988	0.20 - 0.59
Area 4	1987	0.26 - 0.43
	1988	0.41 - 0.58*
Area 5	1987	0.24 - 1.04
	1988	0.28 - 1.13
Issett Lake	1987	0.33 - 1.97
	1988	0.19 - 2.23

* only 2 samples collected

Mercury concentrations in fish from Rat and Threepoint lakes were sampled by the Manitoba Department of

Natural Resources (DNR) from 1983 to 1989. While not part of FEMP, these results are reported here (Fig. 2.22) to help the reader to better understand the mercury problem in the CRD area.

Figure 2.22 Standardized Mean Muscle Mercury Concentrations for Fish in Rat and Threepoint Lakes, 1983 - 1989



Whitefish mercury levels in Rat Lake were stable between 1986 and 1989 at 0.2 µg·g^{-1}; these levels are twice as high as the average for northern Manitoba lakes remote from hydro development (<0.1 µg·g^{-1}) and 2.5 to 4 times the pre-development levels upstream in SIL (0.05-0.07 µg·g^{-1}) and downstream in Wuskwatim Lake (0.08 µg·g^{-1} in 1970). Mercury levels in both walleye and pike declined over the DNR sampling period; however by 1989 levels were still about 3 times higher than the average for northern Manitoba lakes remote from hydro development (0.3-0.4 µg·g^{-1}) and between 3 and 4 times the pre-development level upstream in SIL (walleye: 0.19 - 0.30µg·g^{-1} and pike: 0.26 - 0.32 µg·g^{-1}).

Mercury levels in whitefish in Threepoint Lake, as in Rat Lake, were constant at about 0.2 µg·g^{-1}, between 1983 and 1989. Mercury levels in both walleye and pike, during this period, were highest in 1983 at values of 1.65 and 1.76 respectively, followed by a noticeable decline in 1984. Further smaller declines were recorded between 1984 and 1989; however, 1989 values were still 3 to 4 times higher than northern Manitoba lakes remote from hydro development or pre-development levels upstream in SIL.

Mercury Levels in People

While not part of FEMP, the results of Health and Welfare Canada's (HWC) mercury testing program in South Indian Lake and Nelson House are reported here (Fig. 2.23) to provide the reader with a complete presentation of the available mercury information for the CRD area. Levels of 0 - 19 parts per billion (ppb) are considered to be the normal range for mercury for adults. This value was established by setting a safety factor of one-tenth of the level (200 to 500 ppb) at which signs and symptoms of methyl mercury poisoning would appear in the most sensitive adults. Because prenatal effects may occur at lower levels, women of child-bearing age have been an important target group for sampling by HWC.

Approximately 52% of the population of South Indian Lake was tested for mercury in 1987-1988. Of the people tested, approximately 80% had values in the range of 0-19 ppb; almost all of the remaining values were in the range of 20-50 ppb. For women of child-bearing age, almost 90% had values in the 0-19 ppb range.

Approximately 46% of the population of Nelson House was tested for mercury in 1987-1988. Of the people tested, approximately 90% had values in the range of 0-19 ppb; almost all of the remaining values were in the range of 20-50 ppb. For women of child-bearing age, approximately 98% were in the range of 0-19 ppb.

Figure 2.23 Mercury Levels in Residents of Nelson House and South Indian Lake

Mercury Levels in Residents of Nelson House

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1976	4	1	3	0
1977	59	57	2	0
1978	102	63	38	1
1979	130	71	59	0
1980	0	0	0	0
1981	0	0	0	0
1982	56	50	6	0
1983	24	24	0	0
1984	221	181	39	1
1985	121	93	28	0
1987-88	609	540	69	0

1987-88 Groups	*Sample Number*	*0 - 19 ppb*	*20 - 50 ppb*	*50 - 80 ppb*	*80 - 100 ppb*
Men	268	234	33	1	0
Women:					
12-45 yrs	185	182	2	1	0
over 45 yrs	73	43	29	1	0
Children:					
1-4 yrs	10	10	0	0	0
5-12 yrs	73	71	2	0	0

Mercury Levels in Residents of South Indian Lake

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1977	37	29	8	0
1978	12	9	3	0
1979	100	26	68	6
1980	1	1	0	0
1981	165	102	63	0
1982	389	274	115	0
1983	59	55	4	0
1984	105	70	35	0
1985	56	31	25	0
1987-88	344	274	69	1

1987-88 Groups	*Sample Number*	*0 - 19 ppb*	*20 - 50 ppb*	*50 - 80 ppb*	*80 - 100 ppb*
Men	73	44	28	0	1
Women:					
13-45 yrs	116	104	11	1	0
over 45 yrs	26	13	12	1	0
Children:					
1-4 yrs	77	72	5	0	0
5-12 yrs	52	41	11	0	0

HWC has been regularly testing mercury levels in the residents of all six native communities in the FEMP study area, since the mid 1970s, as part of their national testing program. However, a number of factors make it difficult to assess trends in mercury levels: 1) large variability in the number of community residents tested each year; 2) no identification in the published data record of values from the repeated testing of the same individuals; and 3) annual reporting of test results, which obscures any seasonal patterns.

Future Mercury Studies Along the Churchill River Diversion

The FEMP mercury studies identified several issues relevant to the CRD area that warrant further investigation, as follows: 1) factors affecting microbial demethylation; 2) downstream transport of mercury; 3) the potential of intensive fishing as a means of reducing mercury levels in fish; 4) the complete or partial removal of organic material as a means of preventing or minimizing mercury levels in fish; and 5) a case study of the area of the proposed Wuskwatim Generating Station.

Studies to date have suggested that microbial demethylation rates, like microbial methylation rates, are regulated by organic matter availability and total microbial activity; however, these observations need to be confirmed. There is also a need to determine why demethylation appears to be independent of sediment oxygen conditions, while methylation increases under anoxic conditions. This may provide at least a partial explanation for the differential stimulation of methylating bacteria in flooded reservoir sediments.

FEMP results showed that any methyl mercury in water leaving the Notigi Reservoir is lost before Thompson; the mechanism by which any methyl mercury is lost from the water column in this reach should be determined. Fish movements out of Notigi Reservoir should be quantified to determine if they are making a significant contribution to downstream fish stocks, thereby increasing the mean mercury concentration in fish. In addition, the relative importance of fish and water as the mechanism(s) for downstream transport of mercury remains to be identified.

An investigation of the benefits, costs and long-term impacts on fish resources of intensive fishing as a potential means of reducing mercury levels in fish should be considered. A pilot project could be conducted on those off-route lakes (lakes off of the mainstream of the CRD), with naturally high mercury levels. These lakes are generally smaller and better isolated than those in the CRD making them more suitable for manipulation. Impacts on sport fisheries would also be more easily avoided. Because of these characteristics, these lakes might be a better site to test the effectiveness of intensive fishing than those lakes on the CRD.

Another pilot project which could be undertaken is an evaluation of the effectiveness and an assessment of adverse environmental side effects of the controlled burning of organic matter as a measure to minimize or prevent elevated fish mercury levels in new reservoirs. Preliminary investigations could employ limnocorral experiments to test the ability of various terrestrial organic materials to stimulate microbial methylation and the duration of this stimulation. Field trials in a new reservoir could then be conducted if the initial results of the limnocorral experiments appear favourable.

The reservoir to be created by the proposed Wuskwatim Dam on the Burntwood River would provide an ideal site for the controlled burn pilot project, as well as an opportunity to apply and expand the knowledge of mercury in the CRD generated by the results of the FEMP and CMMA studies. For example, measurements of methyl mercury in water and of methylation and demethylation rates could be taken at the reservoir site and immediately downstream, before the reservoir is created, during the construction period, and immediately after the formation of the reservoir. These data, the first such "pre-" and "early development" data anywhere in the FEMP study area, would be invaluable in refining the mercury duration model. (These data are considered "pre-" and "early development" with respect to the construction of Wuskwatim Dam only. Wuskwatim Lake is not a "pristine" lake; it has already been flooded as a result of the increased flows down the Churchill River Diversion.) In addition, these data if supplemented by data on mercury in fish from the proposed reservoir site and immediately downstream, would provide new information on the understanding of the downstream transport of mercury.

PIKE POPULATIONS IN SOUTHERN INDIAN LAKE

Pike is important to the commercial fishery at Southern Indian Lake: 1) it is the final host in the life-cycle of the parasite *Triaenophorus crassus*, a parasite which lowers the market quality of lake whitefish, the most economically important species of fish harvested in SIL; and 2) it can be an important source of income when whitefish prices are low.

In 1976, DFO initiated a study of pike population in Wupaw Bay SIL, an isolated body of water largely unaffected by the flow of the Churchill River. Although not completely typical of much of post-impoundment SIL because of its short wind fetches and small flooded terrestrial area, this bay offered a sheltered workable area with a good population of pike. The main finding of this 6-year study was a significantly higher pike spawning success in 1977 only, the first year following flooding. It was hypothesized that the flooded terrestrial vegetation immediately following impoundment provided pike with an abundance of substrate on which to lay their eggs and probably also provided a favourable nursery area for the pike fry. A highly successful spawn, combined with an abundance of preferred food and protection from predators were responsible for a highly successful pike year class in Wupaw Bay in 1977. The decline in subsequent year classes was attributed to physical changes in the littoral zone, especially the degradation of the submerged vegetation.

Under the auspices of FEMP, the study of pike populations in Wupaw Bay was extended to 1988 to further examine the effects of impoundment of SIL on the pike and on the forage fish that constitute part of the pike's diet. Throughout the summers of 1982-84 and 1986-88, gill nets were set at sampling sites chosen at random from a total of 36 sites distributed around Wupaw Bay. Length, weight, sex, age, condition factor (a measure of fitness), and stomach contents were recorded for pike captured from gill nets. Once or twice a week each summer five seining stations were sampled by pulling seine nets by hand. The number of fish of each species caught were recorded, identified, and measured.

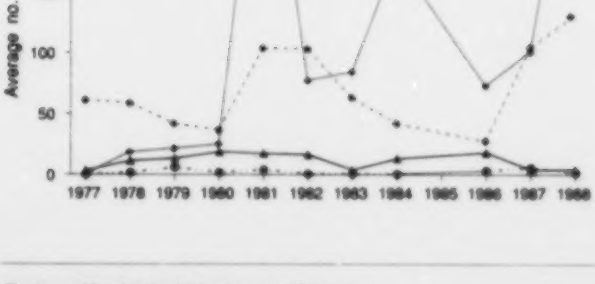
Analysis of the entire data record, from 1976 to 1988, suggest that the adult pike population in Wupaw Bay has suffered since lake impoundment. A downward trend was observed in both catch per unit of effort (from 13.52

per 8 hour period in 1976 to 5.60 in 1988) and in condition factor (from 0.89 in 1976 to 0.84 in 1988). These decreases reflected the status of the entire population; they were not the result of any dominance by the 1977 year class.

The decline in pike abundance appears to be related to physical changes in Wupaw Bay such as an increase in depth (from a range of 0 to 3 m to 0 to 6 m) and a decrease in areas of macrophytes. Before flooding, much of the bay was suitable pike habitat, but since flooding, favoured pike habitat has been restricted to a few peripheral areas where gently sloped shorelines were extensively flooded. A habitat well suited for pike was transformed into one that, at least in relative terms, favoured open-water species. The results of the forage fish study reaffirmed this conclusion.

Shiners (emeralds plus spottails) dominated the seine catches every year, comprising more than 90% of the catch in 7 of the 11 years of seining data. Beginning in 1981, the number of emeralds, relative to the number of spottails, increased noticeably (Fig. 2.24). It is hypothesized that the creation of a deeper clearer body of water in Wupaw Bay (in contrast to the larger basins of SIL) provided a more favourable habitat for the pelagic emerald shiner relative to the more littoral species such as the spottail shiner. It is likely that this stimulatory effect on emerald shiner abundance was limited to Wupaw Bay and similar shallow isolated bays where the post-impoundment increase in mean depth was significant.

Figure 2.24 Average Catch per Seine Haul in Wupaw Bay, Southern Indian Lake, 1977 - 1988



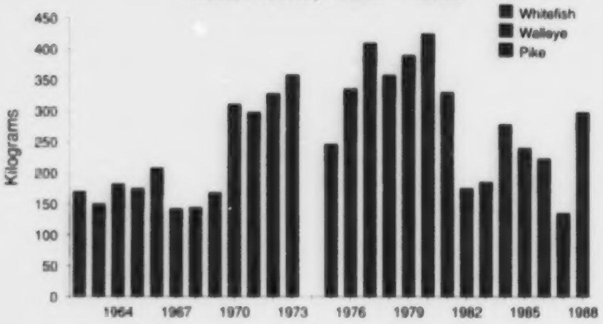
The abundance of littoral species, such as spottail shiner and yellow perch, fluctuated over the study period but showed no overall trend. Spottail shiners were much more abundant in 1982 and 1988 due to high over-winter survival rates of the 1981 and 1987 year-classes respectively, when temperatures were warmer than average. Warmer water temperatures generally result in faster growth of fish, which enhances their ability to avoid predators. Thus, it appears that weather over the open-water season had a greater impact on the abundance of spottail shiners and yellow perch in Wupaw Bay than did the flooding of the lake.

The deterioration in condition of Wupaw Bay pike is thus puzzling, considering the apparently abundant food supply (e.g. shiners, perch) after impoundment of SIL. The percentage of pike stomachs that were empty declined immediately after flooding (from 76% in 1976 to 50% in 1978) then increased slowly to near 1976 levels, by 1988. There was considerable variability over time in the contents of the pike stomachs; for example, the importance of shiners in the pike diet declined after 1977, with the large number of shiners found in stomachs in 1986 being an anomaly to the overall trend. Yellow perch were found in only 4% of stomachs in 1977, increased to 12% in 1981, and afterwards their occurrence in stomachs declined. There seemed to be no relationship between large year classes or overall abundance of forage fish and their occurrence in pike diets.

BIOLOGICAL ASPECTS OF THE WHITEFISH COMMERCIAL FISHERY AT SOUTHERN INDIAN LAKE

The commercial fishery at SIL was the largest in northern Manitoba prior to impoundment and diversion with about 333,500 kg of fish taken yearly. Approximately 85% of the total commercial catch weight was composed of lake whitefish, with the rest being made up of pike and walleye (Fig. 2.25). Immediately following impoundment there was a substantial drop in catch per unit effort (CPU) (Fig. 2.26). In 1982, the whole whitefish catch of the lake was downgraded from export to continental grade, with a concomitant substantial drop in fish price. The lower price and reduced CPU led directly to a collapse of the commercial fishery.

Figure 2.25 Yearly Catch of the Three Main Commercial Species at Southern Indian Lake, 1962 - 1988



Under the auspices of FEMP, a biological assessment of the post-impoundment commercial fishery at SIL was undertaken, with quantitative data collected for the 1987 open-water season and qualitative data only for the 1988 season. Data were obtained through interviews with commercial fishermen, from field studies, and from a review of the catch records from the Freshwater Fish Marketing Corporation (FFMC), a Crown corporation owned by the federal government which holds a virtual monopoly on the sale of freshwater fish in parts of Canada, including Manitoba. The FEMP sponsored study focused on the fish delivered to the Missi Falls plant since they comprised the majority of the SIL commercial catch. Information was collected on whitefish numbers, length, weight, age, colour, grade, cyst count, CPU, catch location, and seasonal analysis of catch.

The 1987 data showed that CPU was still depressed in comparison to pre-impoundment levels, both for Region 4, historically the most important commercial fishing area of SIL, and for Regions 4 and 5 combined, where more of the post-impoundment fishing activity is occurring (Fig. 2.26). The number of days nets are left in one location has been reduced from a pre-impoundment average of 18 days to an average in 1987 of 6.3 days in Region 4 and 5.0 days in Region 5. Frequent relocation of nets (e.g. due to fouling by debris and/or non-commercially valuable rough fish) reduces the amount of time that nets are in place for catching fish, and increases fishing effort. However, both CPU and number of days nets left in one location were higher in 1987 than in 1981. (The most important factor affecting CPU, the abundance of fish and their movement, is discussed in the next section.)

The 1987 open water season had one of the lowest total catch weights of the last 25 commercial open water seasons (140,000 kg) and one of the lowest whitefish percentage of catch (46%) (Fig. 2.25). Pike comprised an unusually high proportion (42%) of the total 1987 commercial catch. The 1988 fishery was more comparable to the pre-impoundment fishery in total catch weight (300,000 kg) and species composition (whitefish percentage of catch was 85%).

A major factor for the differences between the 1987 and 1988 open-water seasons was the higher whitefish prices in 1988. The low whitefish prices in 1987 promoted a dichotomy in the fishery, with pike being the favoured species in the spring (comprising approximately 61% of the catch) and whitefish being the favoured species in the fall season (comprising approximately 93% of the catch). Greater movements of pike in

Figure 2.26 Selected Statistics for the Open Water Commercial Fishery at Southern Indian Lake

	1987 *R.4*	*1987* *R.4/5*	*1981*	*1980*	*1979*	*1972*
Catch per unit effort (kg/n.n)	8.44	9.75	7.50	10.30	15.50	23.10
% Whitefish export grade	37.00	33.00	19.00	66.00	28.00	100.00
Mean cyst count per kg dressed	1.05	1.20	1.16	1.09	1.22	0.53
Mean cyst count per shipment	51.90	61.40	57.20	54.20	79.10	23.10
% light colored whitefish	66.00	59.00	14.00	65.00	28.00	100.00
% Whitefish in commercial catch*	71.00	46.00	79.00	89.00	81.00	91.00
% Total effort	58.00		67.00	70.00	38.00	100.00
Days net left at one location	6.30	5.00	5.60	5.00	7.00	18.00**
Whitefish mean age***	9.80	9.70	10.20	10.40	9.95	9.10

* Data from FFMC, except 1987, Region 4, from FEMP study

** Pre flood average

*** From fin ray sections except 1972, from scale analysis the spring and whitefish in the fall, due to spawning activities, make them easier to catch at those times of the year. The shift in effort between species appeared to reflect an opportunistic attempt by the fishermen to continue fishing by exploiting those species with the best chance of large economic returns. (Another reason for the higher catches in 1988 would have been the introduction of the 12.7 cm mesh nets into the whitefish fishery; the slightly smaller mesh size would have increased the catch because whitefish should have been more vulnerable to being caught in the smaller mesh.)

Fish prices are extremely important to a commercial fishery in a northern lake, like SIL, that is remote from southern markets. Whitefish prices can vary substantially depending on the grade - export, continental, or cutter (Fig. 2.27). Grade classifications are based on the number of *Triaenophorus crassus* cysts present per 45 kg of whitefish (dressed weight): export grade, 0 to 40 cysts per 45 kg; continental grade, 41 to 80 cysts per 45 kg; and cutter grade, over 80 cysts per 45 kg.

Figure 2.27 Fresh Whitefish Prices, Summer 1988, FOB Station - Leaf Rapids

	Grade	$./kg
Whitefish	sml (.45-.7)	0.412
Export	med (.7-1.4)	0.792
Dressed	lge (1.4-1.8)	0.812
	Jmbo (over 1.8)	0.832
Whitefish	sml (.45-.7)	0.302
Continental	med (.7-1.4)	0.412
Dressed	lge (1.4-1.8)	0.412
	Jmbo (over 1.8)	0.412
Cutters/Hdls	all sizes	0.372

The average cyst count for fish sampled in 1987 under the FEMP study were: Region 4, 51.9; Region 5, 74.1; and the southern portion of the lake that delivers to the community, 81.1. Data on the cyst counts in whitefish in 1987 were further analyzed by sub-areas of Region 4, and by colour of whitefish. The cyst count for Region 4A was 59.9, Region 4B was 21.3, and Region 4C was 64.1. Except for Region 4B, where the sample size was small, the grade was still continental. Analyses of the sampled whitefish by colour showed that 65% of the export whitefish were light coloured and that the chance of a light whitefish being export was 48%. Thus, it appears that neither selective fishing by sub-area of Region 4, the traditional export grade area of SIL, nor by colour for light whitefish, would likely result in a reclassification of the commercial catch from continental to export. However, it should be noted that in 1987 Region 4 still produced the highest quality fish of the sampled regions.

The higher cyst counts found in the whitefish from Region 5, in 1987, agreed with historical evidence that Region 5 produced poorer quality whitefish than Region 4. Previous research (Johnston 1984) found that conditions favourable for higher cyst levels are more prevalent in Region 5 than in Region 4, due to the shallower mean water depth and the larger numbers of pike, the final host in the parasite cyst cycle. Bodaly et al. (1980) indicated that decreased light penetration after flooding could have caused whitefish to spend more time in shallow water. This would bring them into a situation where there is an increased probability of cyst infestation, as a result of co-inhabiting with pike where pike are more prevalent. Another factor which may result in higher average cyst counts in the commercial catch is the harvesting of smaller whitefish, through the use of nets with smaller mesh sizes, since larger whitefish can have lower rates of cyst infestation.

Age analysis of the 1987 sampled whitefish showed that the majority of individuals were between 8 and 11 years; the mean age (9.72) was quite similar to that found from 1979 to 1981 (9.95 - 10.40). There was very little difference between Regions 4 and 5 in the overall age structure of the sampled catch. Earlier studies (Ayles 1976) found similar mean ages. The age distribution of the commercial catch suggests that SIL is a light to moderately exploited commercial whitefish fishery; this low level of commercial exploitation would render unlikely any hypothesis that would consider over fishing as a causal factor in the decreased CPU levels on traditional fishing grounds.

The results of the biological assessment of the SIL fishery suggest that: 1) the fishery may be stabilizing at levels lower than pre-impoundment values or that a marginal improvement may be taking place; 2) a return to an export quality fishery will not be an option, at least not for the immediate future; and 3) there was a shift in the geographical distribution of fishing effort from Region 4 to Region 5 in response to higher catches of preferred species.

WHITEFISH DOWNSTREAM OF MISSI FALLS

Bodaly et al. (1984) suggested that declines in catch per unit (CPU) effort in SIL may be due to major movements of fish out of the lake in response to changes caused by impoundment. Large numbers of whitefish have been observed congregating immediately downstream of the Missi Falls Control Structure on SIL. The objective of one FEMP-sponsored study was to estimate the numbers and seasonal pattern of lake whitefish abundance below Missi Falls and to determine the origin of these fish.

Whitefish were live sampled below Missi Falls, 5 times in 1986 and 4 times in 1987 during the open-water seasons. Fish in each sampling group were given a distinctive marking (e.g., dorsal fin clip) that distinguished them from the other sampling groups. Recapture of previously marked fish provided estimates of population numbers below the Missi Falls Control Structure. Samples were also obtained to provide morphological and biological comparisons with whitefish caught at 2 upstream locations, Region 4 and near Strawberry Island in SIL, and at 4 downstream locations, Partridge Breast, Northern Indian, Fidler and Gauer lakes. Morphological differences among whitefish are invaluable in indicating stock discreteness, especially in instances where genetic differences do not exist, as was the case for whitefish in the Missi Falls area (Bodaly et al. 1984). Biological data were used to compare the health and reproductive readiness of the sampled whitefish.

Large numbers of fish were caught below Missi Falls in both study years, with whitefish dominating the catch for nearly all sample times. Estimated whitefish populations ranged from a low of 10,701 in July 1987 to a high of 88,764 in September 1986. (Fig. 2.28). In addition to the significantly larger number of fish present below Missi Falls in 1986 than in 1987, there was also a difference in the seasonal distribution. In 1986, estimated population numbers gradually increased over the summer reaching a peak in the autumn; in 1987, however, the population numbers peaked early in the summer.

Examination of the morphological data set, without the Missi Falls samples, indicated that fish from the upstream and downstream areas were quite morphologically different from one another. Because of the long sampling period, from June 1986 to October 1987, there was a concern that temporal, rather than spatial, differences might have been responsible for the observed morphological differences between upstream and downstream sites. However, there was some evidence to suggest that morphological changes among locations did not represent regular seasonal changes within a single population. For example, if changes in morphology were largely due to seasonal changes, then the changes observed over time at Missi Falls in 1986 would have been reflected in the changes during the 1987 period; this was certainly not the case.

Figure 2.28 Estimated Whitefish Population at Missi Falls

Date	Number of Fish tagged	Estimated Pop Size	s.d.
Jun-86	355	-	-
Jul-86	598	13942	5744
Aug-86	610	44818	20528
Early Sep-86	2794	88764	21415
Late Sep-86	1577	88567	23042
Jun-87	3235	28867	5640
Jul-87	2529	10701	1625
Aug-87	1856	13454	3242
Sep-87	953	-	-

Comparison of the morphological data on the whitefish sampled at Missi Falls to the data on the whitefish sampled at the upstream and downstream sites showed, in general, that the Missi Falls fish caught in the autumn of 1986 most resembled the closest upstream samples, whereas the Missi Falls fish caught in the summer of 1987 most resembled the closest downstream samples. Thus, it was concluded that most of the whitefish at Missi Falls in 1986 appeared to have originated from upstream, in SIL, while in 1987 most of the Missi Falls whitefish appeared to have originated from the downstream lakes on the lower Churchill River.

Analysis of the biological data showed that the Missi Falls fish caught in 1987 were experiencing greater physiological stress than the 1986 fish sampled (e.g. the 1987 fish had significantly thinner bodies than the 1986 fish and had more empty digestive tracts) (Fig. 2.29). Gonad somatic indices (GSI), a measure of reproductive readiness, increased almost exponentially in 1986 for both males and females, but decreased over the 1987 sample season until autumn (Fig. 2.30).

Thus, there were marked differences in the characteristics of the whitefish populations below Missi Falls in 1986 and 1987. In 1986, a year of high discharge over Missi Falls: 1) there was a large number of whitefish present; 2) the numbers peaked in the autumn; 3) the fish were well-fed and in good condition; and 4) the majority appeared to have originated from SIL. It was concluded that they were trying to return to SIL to spawn. In 1987, a year of lower flows and higher water temperatures than 1986 (Fig. 2.31): 1) the number of whitefish present was lower than in 1986; 2) the numbers peaked in the summer; 3) the fish were in poorer condition than in 1986; and 4) the majority appeared to have originated from the downstream lakes. It was concluded that they were trying to escape the warmer waters of the downstream lakes.

It would appear that the reduction in CPU in SIL has been greatly influenced by the construction of the Missi Falls Control Structure. This study suggests that even 10 years after the impoundment of SIL, there are still significant numbers of lake whitefish attempting to complete the traditional migration. Future consideration should be given to mitigating measures which could involve a seining program at Missi Falls to transport fish upstream

Figure 2.29 Whitefish Digestive Tract Fullness, Missi Falls, 1986 and 1987

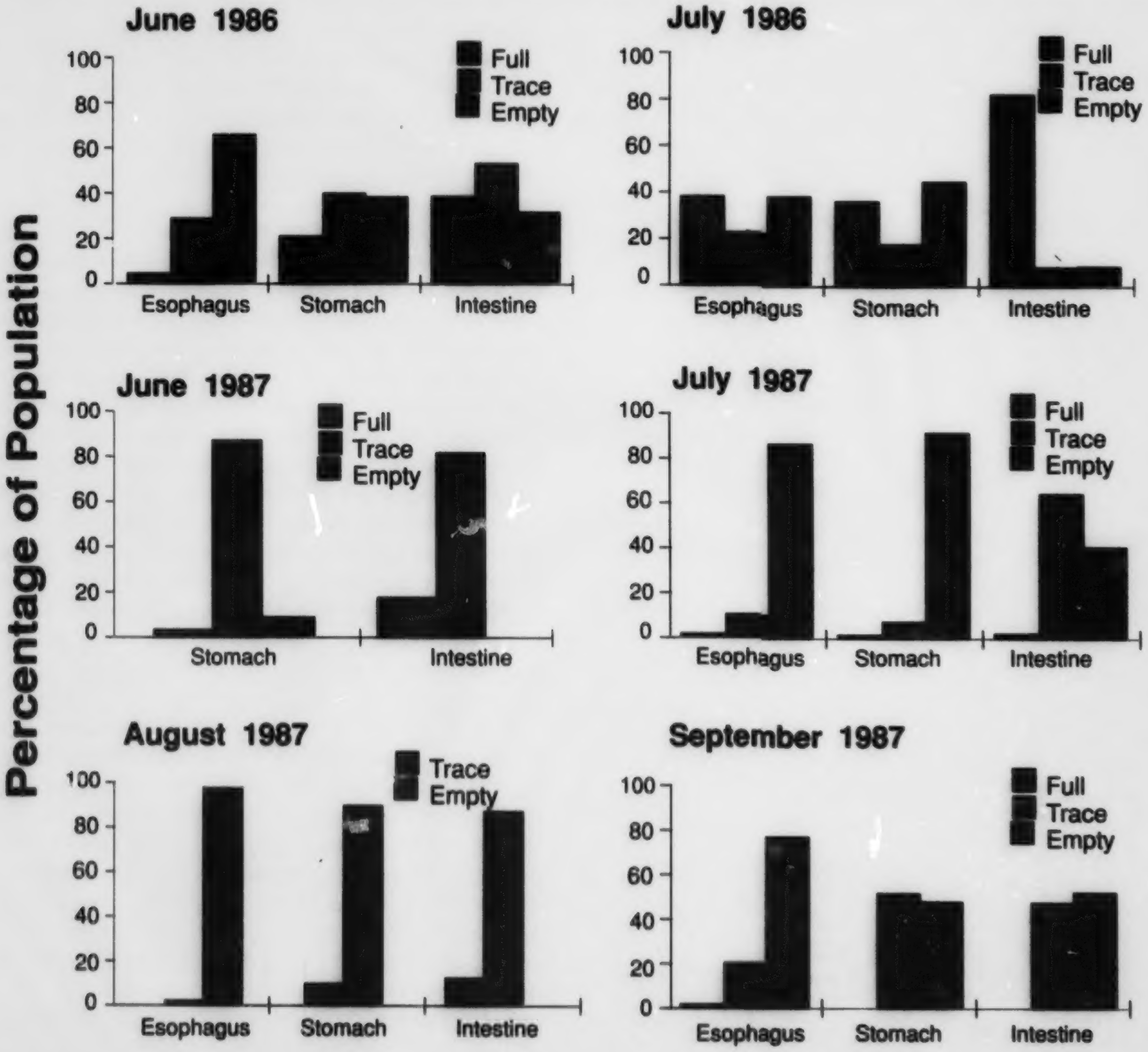


Figure 2.30 Temporal Changes in Gonad Somatic Index (GSI) for Whitefish at Missi Falls, 1986 and 1987

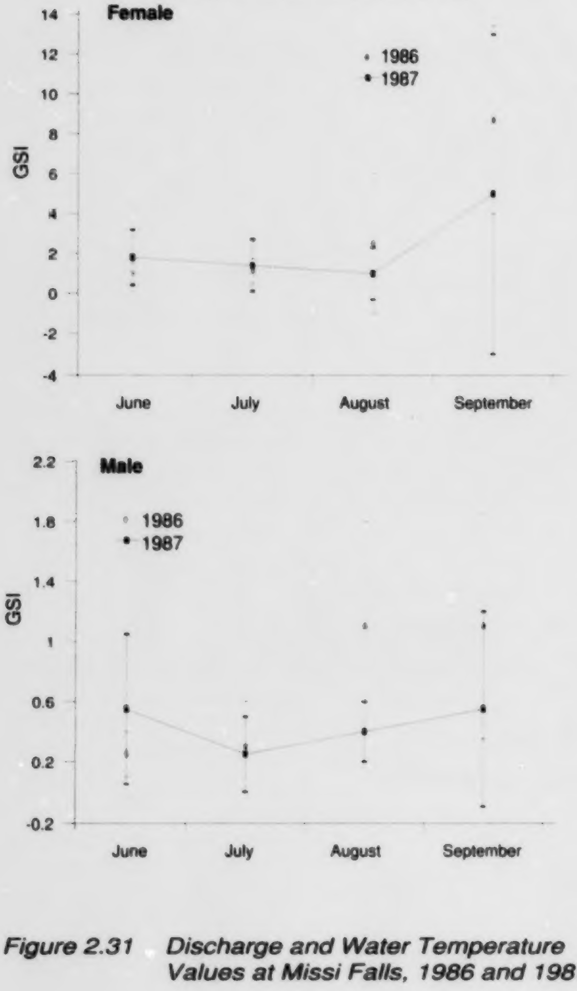
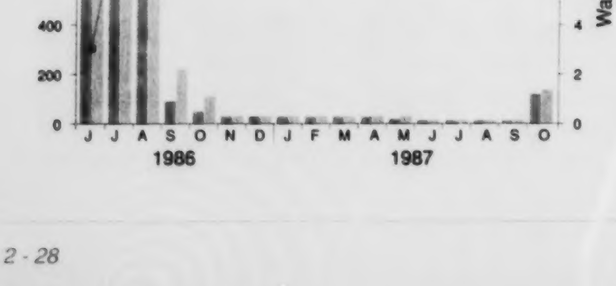


Figure 2.31 Discharge and Water Temperature Values at Missi Falls, 1986 and 1987



over the dam at critical periods when fish are attempting to move upstream.

THE ECONOMIC PERFORMANCE OF THE SOUTHERN INDIAN LAKE COMMERCIAL FISHERY

Since its inception in 1941, the commercial fishery at Southern Indian Lake has been a major component of the South Indian Lake economy. For example, it was estimated that in 1972, the last year before work began on raising the water level of SIL, the fishery was the single most important source of livelihood in the community, providing 43% of the community's income. However, following impoundment, the commercial fishery collapsed. Studies of the economic performance of the summer fishery at Southern Indian Lake in 1977 and 1980 showed that the net income per firm, without taking into account compensation, dropped from $1964 in 1977 (in 1980 dollars) to a loss of $304 in 1980 (Wagner 1984).

A FEMP sponsored study reassessed the economic health of the commercial fishery in 1988. Techniques used in this study included field research conducted between June 8, 1988 and September 5, 1988; participant observation, (e.g. accompanying fishermen onto the lake as an extra helper); conversations with fishermen, including the use of formal interviews with structured questionnaires; and a review of the data made available by the Freshwater Fish Marketing Corporation (FFMC). These techniques provided data on 23 firms, which represented 81% of the active fishermen on SIL. Fishing revenues and costs were calculated from 3 perspectives: 1) direct comparison to the 1980 study categories; 2) an approximation of the fishermen's view of the economics of the fishery; and 3) an estimation of the total community income from the fishery.

In 1988, the fishery produced an average net income for the fishermen of $8289 (Fig. 2.32). This calculation included an allowance for capital depreciation, and payments from hydro compensation and freight subsidies that in 1988 combined to provide 36% of the total revenue; without these supplements, the economic future of the fishery would be less secure. The average net income per firm was substantially higher for firms delivering to Missi Falls ($13754) than for firms delivering to the community of South Indian Lake ($4776). This difference was due primarily to the difference in the size of the average catch for firms in each region, 139,113 kg or 15,475 kg/firm, for the Missi Falls area and 81,596 kg or 5,828 kg/firm for the south end of the lake. There were also small differences between the two regions in average cost per kilogram of fish (the north end cost was $0.80 versus $0.89 in the south end) and in average revenue per kilogram of fish (the north end was $1.69 versus $1.72 in the south end). Differences in economy of scale for the larger catches in the north end and differences in species composition of the catches likely accounted for these small differences.

The average net income per firm increased from $6,300 in 1980 (in 1988 dollars) to $8,289 in 1988, an increase in real income of 32% (Fig. 2.32). The most important reason for this increase was a substantial increase in continental and cutter grade whitefish prices in 1988, the only grades now produced since the loss of the export grade rating for SIL in 1982 (Fig. 2.27).

Revenues from the SIL fishery since 1980 have also been affected by a change in the administration of the compensation fund. From 1978 to 1983, compensation to SIL fishermen varied depending on species, grades, and the area of the lake in which the fish were caught. Since 1983 a $2.5 million compensation fund, administered by the South Indian Lake Fishermen's Association, pays

Figure 2.32 Aggregate and Average Net Incomes of Sampled Firms in Southern Indian Lake, 1980 and 1988

Items/Year		1988		1980
	SIL Deliveries	Missi Falls Deliveries	Aggregate	
Revenue				
Sales	$ 91947	$ 148337	$ 240284	$ 233150
Hydro Compensation	25356	47470	72826	68088
Freight Subsidies	23089	39792	62881	58803
Total	$ 140392	$ 235599	$ 375991	$ 360041
Costs				
Food & Fuel	27944	40906	68850	57369
Repairs	2231	2968	5199	8807
Fishing Gear	3023	2509	5532	18474
Hired Labour	1050	7610	8660	nil
Boat Charges	2255	24075	26330	41593
Truck Charges	10897	3126	14023	n/a
Ice Harvest	1768	3061	4829	n/a
Licenses	330	210	540	580
Insurance	nil	nil	nil	473
UIC	968	622	1590	2400
Miscellaneous	300	0	300	2178
Total	$ 50766	$ 85087	$ 135853	$ 131874
Depreciation				
Boats	4268	4150	8418	7412
Motors	11460	13760	25220	35970
Nets	5082	3798	8880	24333
Camp Gear	514	1025	1539	1436
Total	$ 21324	$ 22733	$ 44057	$ 69151
Interest	1431	3989	5420	7816
Aggregate Net Income	$ 66871	$ 123790	$ 190661	$ 151210
Average Net Income	$ 4776 (14 firms)	$ 13754 (9 firms)	$ 8289 (23 firms)	$ 6300 (24 firms)

NOTE: All values are in 1988 $, n/a = not applicable one amount for all commercial species from all areas of the lake and from certain outlying lakes. In 1988 this amount was $0.33/kg.

Another change that has occurred in the SIL fishery since the 1980 study was the introduction of a regular ferry service to the community in 1985. The daily transport of the fish catch to Leaf Rapids which regular ferry services enables, along with the south end's warmer temperatures, less rough waters, and close proximity to the community has led to the development of a community-based fishery in the south end of SIL, despite the smaller catches in comparison to the lake's north end. Greater commitment is required to fish in the less hospitable north end of the lake, with 10 to 12 hour days not uncommon for firms in this area in 1988. All of the fishermen in this area lived in camps located near where they were fishing, with trips to the community, a 2 hour boat ride, by these fishermen being relatively infrequent.

An analysis of the economics of the fishery from the fishermen's view differed from the preceding analysis in the following ways: 1) payments by the fishermen to the Manitoba Agricultural Credit Corporation (MACC) were used to represent the cost of capital items; 2) the cost of nets and camp gear purchased were used in place of the calculation of depreciation of these items; and 3) UIC benefits, as well as costs, were included. The resulting calculation, (Fig. 2.33) is significant because it more closely reflected the net cash income that was received by the fishermen. Using this form of analysis, the average net income per firm was $9,751.

An estimate of the total community income from the fishery was generated by calculating: 1) total estimated net income from the commercial fishery at SIL; 2) the value of the income-in-kind that resulted from the pursuit of the commercial fishery at SIL; 3) estimated net income for SIL fishermen from the inland lakes fishery; and 4) unemployment insurance benefits received by SIL fishermen. Total community income from the commercial fishery on SIL was estimated by assuming that the revenues and costs/kg of the firms not surveyed were similar to those firms which were surveyed. The aggregate revenues and costs of all firms were then calculated by using the ratio of the total number of kilograms of fish caught in SIL overall (267,908 kg) to the total caught by the firms surveyed (220,709 kg), i.e. 1.21:1. Multiplying the numbers in Fig. 2.34 by 1.21 gave an estimated total community income of $232,326. (In this calculation, UIC premiums were not included and the license cost was changed to $950, since 95 licenses were issued to the community.) If the wage labour paid out by the firms is added back in, the total estimated net income to the community in 1988 rises to $242,631.

Income-in-kind to the community that resulted from the pursuit of the commercial fishery activity at SIL was estimated as the value of domestic fish consumption and of moose shot while fishermen were on the lake fishing. Two estimates of domestic fish consumption were used: 1) an average consumption of 60 kg per person per year, based on studies done by various researchers in native communities across the north; and 2) an estimate of 30 kg per person per year, because of the ready availability of store bought goods in the community as well as in Leaf Rapids. Assuming a price of $4.00 per kg the value of the domestic fish consumed was estimated at $120,000 to $240,000. (It was observed that the fish consumed were commonly not of commercial value; i.e. they were either not a commercially valuable species, such as red sucker,

Figure 2.33 An Alternative Analysis of the Net Income of the Sampled Firms in Southern Indian Lake, 1988

Revenue	
Sales	$240,284.
Hydro Compensation	72,826.
Freight Subsidies	62,881.
UIC Benefits (estimated)	45,269.
Total Revenue	$421,260.
Costs	
Food and Fuel	68,850.
Repairs	5,199.
Fishing Gear	5,532.
Net Purchases	6,456.
Hired Labour	8,660.
Licenses	540.
Boat Charges	26,330.
Truck Charges	14,023.
Ice Harvest	4,829.
Camp Gear Purchases	465.
UIC Premiums	1,590.
Miscellaneous	300.
Total Operating Costs	142,774.
MACC Payments (incl interest)	54,216.
Aggregate Net Income	$224,270.
Average Net Income	$9,751. (23 firms.)

or they had been slightly damaged in the nets.) An estimated 20 moose were killed during the fishing season by SIL fishermen; most were opportunistic kills that would not have occurred had the people not been in the area fishing at the time. Each moose was valued at a minimum of $2,300 which reflected an estimated value of 250 kg of meat at $8.00 per kg and a value for the hide of $300.00. The total income-in-kind was thus estimated at $166,000 to $286,000.

In the 1980s, some SIL fishermen also began fishing nearby lakes, with financial assistance provided by the SIL Fishermen's Association to offset the higher transportation costs. Data collected in 1988 suggest that the inland lake fishery was more lucrative than the SIL fishery; the average income for 5 firms surveyed that operated on the inland lakes out of Missi Falls was $10,143 per firm. Access to the inland lakes fishery is limited, however, by the relative scarcity of lakes suitable for commercial fishing in the region, the limited availability of inland lake licenses, and the high start-up cost of operating on an inland lake.

Employment provided by the commercial fishery at SIL enabled 13 fishermen to meet eligibility requirements for unemployment insurance benefits, providing a net benefit to the community of $52,875. The limited availability of alternative forms of employment in SIL emphasizes the importance of this benefit.

Total community income from the commercial fishery in 1988 was estimated, roughly, at $512,221 to $632,221 consisting of: 1) net income from the SIL commercial fishery, including wages to hired labour, of $242, 631; 2) income-in-kind of $166,000 to $286,000; 3) net income for 5 SIL fishing firms from the inland lakes fishery of $50,715; and 4) unemployment benefits to SIL fishermen of $52,875. All of this income was directly dependant on the economic viability of the commercial fishery at SIL (e.g. provision of capital items, employment opportunities, etc.) Data collected on the summer commercial fishery in SIL in 1988 suggests that the future of the commercial fishery is financially secure; however, it is important to note that 36% of that year's revenue was from a compensation fund and a freight subsidy program. High whitefish prices in 1988 were also important; they were the major reason for the 32% increase in real income since 1980.

BENTHIC INVERTEBRATES

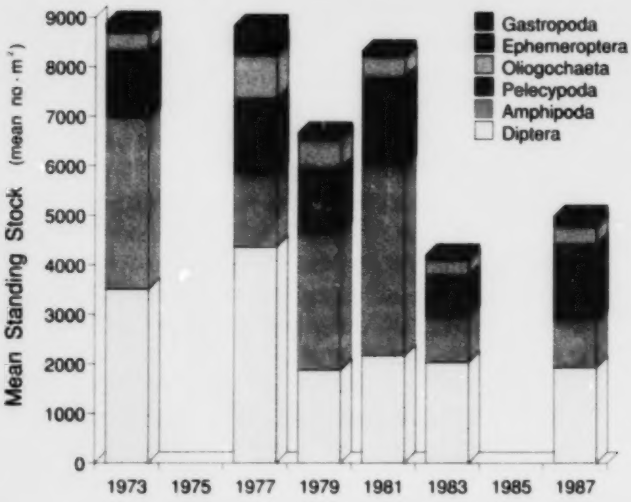
Benthic invertebrates are a major food source for bottom feeding fish. In 1973, a survey was initiated of the lakes along the diversion route and in the lower Churchill River to assess the potential effects on benthic invertebrates caused by the hydroelectric manipulations. The lakes surveyed along the lower Churchill River were: Partridge Breast, Northern Indian, and Fidler; those flooded by the Notigi Reservoir were: Karsakuwigamak, Rat, Notigi, West Mynarski, and Central Mynarski; and those below the Notigi dam were: Wapisu and Wuskwatim. Two other surveyed lakes, East Mynarski and Wood, were unaffected by water manipulations and were intended as reference sites.

The initial survey (1973) was repeated in 1977 and every two years until 1987, with the exception of 1985; the 1987 survey was conducted as part of the FEMP. Samples were taken at 3-10 sites in the profundal area of each lake and consisted of one Ekman grab per site, screened through 400μm mesh netting. Physical and chemical data were also collected. Fidler Lake was deleted in 1979 because of drying; similarly, other sites were deleted when it became hazardous to land a float plane. To examine statistical differences in invertebrate populations before and after diversion impacts, analyses of variance were conducted on lakes, or groups of lakes, with sufficient stations.

The lakes surveyed along the lower Churchill River had reduced flow, and greatly reduced volume and surface area, but maintained a similar water exchange rate. These lakes suffered a decline of one-half of the profundal invertebrate standing stock over a decade, in addition to losing approximately 46% of their area (almost the entire productive littoral zone) (Fig. 2.34). Although a concentrating effect may have occurred initially from the littoral to the profundal zone, with the invertebrates moving into deeper water like the fish of Cross Lake, the majority of benthic invertebrates were limited by available habitat, their size and swimming ability, and likely desiccated in the dried littoral zone. Establishment of a new littoral zone has been hampered by fluctuations of water released from the Missi Falls dam, and therefore it is unlikely that these lakes will regain their productivity. Like the fish of Cross Lake, the benthic invertebrates of the lower Churchill River will maintain reduced populations, primarily below the range of water level fluctuations.

Trends in total standing stocks varied with each lake as

Figure 2.34 ***Mean Standing Stock of Benthic Invertebrates in the Lower Churchill River Lakes, 1973 - 1987***



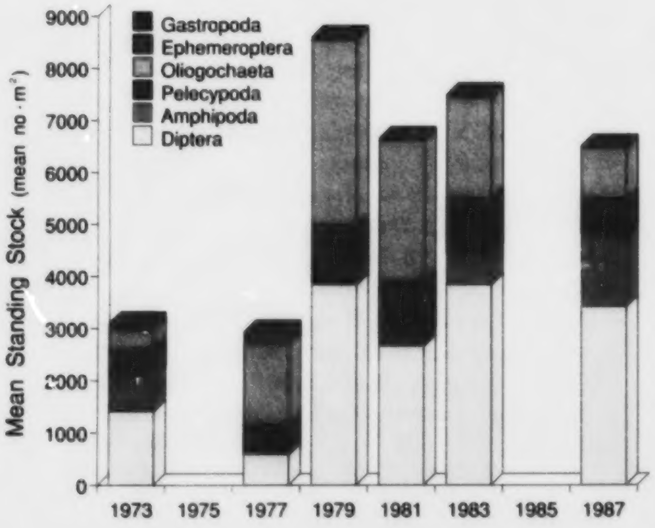
follows: 1) Partridge Breast Lake - decreased from 23743 organisms m^{-2} in 1973 to 6740 organisms m^{-2} in 1987; 2) Northern Indian Lake - 5585 organisms m^{-2} in 1973, followed by a temporary increase in the late 1970s to 35-48% above pre-impact levels, falling to approximately one-half of pre-impact values in 1983; 1987 values were lower than those of 1973; 3) Fidler Lake - standing stocks in the initial years resembled those of Northern Indian Lake, however continued sampling was impossible because of desiccation of much of Fidler Lake. Two immediate responses of invertebrate taxa to lowered water flow involved an immediate decline in number of Amphipoda and a temporary increase in Ephemeroptera numbers. For most taxa, the overall trend one decade after the impact occurred was one of decline to abundances lower than before flow manipulations.

Notigi Reservoir followed a sequence of events which is typical for a new reservoir. Effects ranged from deoxygenation of the hypolimnion, to increases in dissolved nutrients and particulate organic matter derived from flooded vegetation, to a resulting bloom of phytoplankton, bacteria and invertebrates; these lower trophic levels support higher trophic levels. Productivity brought on initially by the additional nutrients and particulate food resulted in increases in benthic invertebrates to levels seen only in the lower Churchill River before damming. One major difference in the response of Notigi Reservoir in comparison to most new reservoirs is that it has not, yet, experienced a subsequent decline in populations of benthic invertebrates. Although total benthic standing stocks declined slightly in later years, the anticipated decrease had not occurred by 1987, likely because the Churchill River itself was a major source of nutrients to the reservoir. (Fig. 2.35). Benthic invertebrate productivity is likely to remain high in this reservoir particularly with the continued input of nutrients from the diverted Churchill River, the relatively small drawdown, and the eventual development of stable benthic habitat as shoreline erosion ends and flooded vegetation disappears.

The faunal composition in 1973 of the lakes that formed the Notigi Reservoir was diverse, and considerable numbers of the six major taxa were present. The composition seen in 1977, however, was substantially different: the Amphipoda and the Ephemeroptera disappeared from all of the lakes after initial flooding, leaving the Diptera, Pelecypoda, and Oligochaeta to provide most of the benthic abundance. By 1981, the standing stock was down approximately 25% but species diversity was returning, and Amphipoda were again regularly found in the samples. By 1987, taxa richness overall reflected the pre-impoundment conditions of 1973, with all of the taxa except the Pelecypoda having almost doubled in abundance.

Wapisu and Wuskwatim lakes experienced a similar sequence of events in which an initial high, post-impact

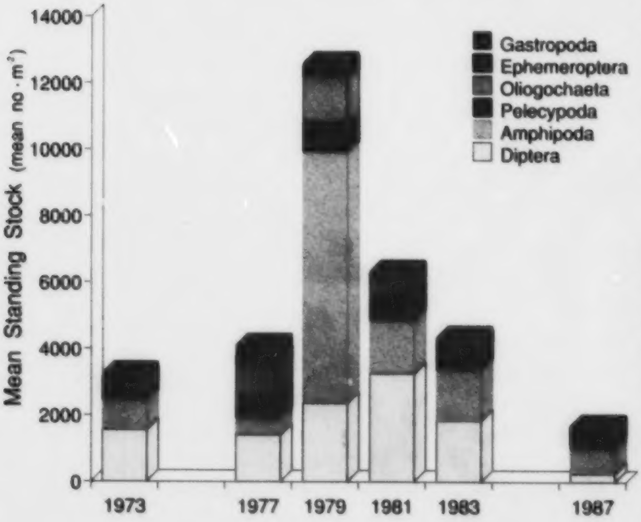
Figure 2.35 ***Mean Standing Stock of Benthic Invertebrates in the Notigi Reservoir Lakes, 1973 - 1987***



productivity, based largely on benthic organisms feeding on drowned vegetation, was followed by a trophic depression when organic matter was exhausted or rendered unavailable by siltation. (Fig. 2.36). However, the extent of the changes differed between these two lakes. Wapisu Lake nearly always had higher standing stocks than Wuskwatim Lake; pre-impoundment totals were 2.5 times higher. With the influx of Churchill River water in 1977, and consequent increase in depth, the diverse benthic fauna responded by increasing in total abundance to 12,600 organisms m^{-2} in 1979 from 4245 m^{-2} in 1973. By 1987 total standing stocks had decreased to 1602 organism m^{-2}. The proportions of taxa in 1987 were similar to those of 1973, but with fewer Diptera.

Total standing stocks in Wuskwatim Lake doubled in 1977 to 3197 organism m^{-2} from 1644 m^{-2} in 1973; they subsequently declined to 1819 m^{-2} in 1987. Although the fauna of Wuskwatim Lake was less abundant than in Wapisu Lake, the same taxa were present. Proportionally, however, Ephemeroptera and Gastropoda were more abundant in this benthic community. The response of the benthic community in this lake was similar to that in Wapisu Lake but of lower amplitude. The intervening Threepoint Lake and approximately 55 km of river between the two lakes may have moderated the response of the invertebrates in Wuskwatim Lake.

Figure 2.36 ***Mean Standing Stock of Benthic Invertebrates in Wapisu and Wuskwatim Lakes, 1973 - 1987***



The two reference lakes, Wood and East Mynarski, showed some variation in standing stocks over time, but most especially East Mynarski Lake. Total numbers in East Mynarski Lake fluctuated considerably without apparent pattern during the course of the study; however, the total standing stock was always higher in surveys done after 1973. In Wood Lake, the total standing stocks after 1973 were not significantly different from one another; 1973 stands alone with low numbers. Total invertebrate standing stocks of this lake were usually about one-half of the riverine lakes, indicating the extent of the influence of river-borne nutrients and their effects on benthic populations.

In summary, standing stock for the lower Churchill River lakes is about 50% of pre-development levels, on a per-area basis. Loss of almost half of the most productive lake areas has meant that the present total population of benthic invertebrates is only about 25% of that before diversion, a major loss of food resources for bottom feeding fish. Standing stock in the Notigi Reservoir has stabilized at about twice the pre-impact levels, which combined with an areal increase of approximately four times, means that the present water body has approximately eight times more benthic invertebrate standing stock than previously. Future levels of standing stock for this reservoir depend on the continued supply of nutrients from the Churchill River, but should remain higher than pre-impoundment levels.

WATERFOWL

Concerns expressed by the Nelson House Band members that opportunities to hunt waterfowl in the fall had declined after the diversion of the Churchill River resulted in a FEMP study of waterfowl in this area. The purpose of this study was to investigate current waterfowl use in the fall and to the extent possible, compare it with historical usage.

One-on-one interviews were conducted with 7 waterfowl hunters in Nelson House on February 19, 1988. Hunters were asked to describe their waterfowl hunting experiences and to share their observations on changes in the numbers and distribution of waterfowl; this information was used in the determination of the timing and location of the waterfowl surveys in this area. On September 1, 9, and 26, 1988, a series of low-altitude aerial surveys were flown using a Bell 206B helicopter with one observer. Survey routes followed the shorelines of

Wapisu, Threepoint, Wuskwatim and Honeymoon lakes and the Rat-Burntwood rivers (Fig. 2.37). Notakikwaywin Lake, which is located off of the CRD was also surveyed on September 26, 1988.

A summary of the 1988 survey data are shown in Fig. 2.38. Maximum numbers and densities are recorded because they were more likely to represent the potential for waterfowl use. Low numbers of ducks and Canada geese were observed in all surveyed areas, with the exception of the single survey of Notakikwaywin Lake where duck densities were considerably higher. There was considerable variability in the numbers of ducks and Canada geese observed between surveys and sites, (e.g. along the Rat River a total of 4 ducks were observed on September 1, 1988 and 44 on September 9, 1988).

The only historical data on waterfowl use of this area are the results of a 1973 aerial survey (LWCN 1975); these data are summarized in Fig. 2.39. Honeymoon and Notakikwaywin lakes and the reach of the Burntwood River upstream of Threepoint Lake were not surveyed in 1973; other areas surveyed in 1973 are, in general, comparable with those surveyed in 1988. As was the case with the 1988 survey, there was considerable variability in the numbers of ducks and Canada geese observed between surveys and sites in 1973 (e.g. 72 dabbling ducks were observed at Wuskwatim Lake on September 7, 1973 and 944 on September 26, 1973).

Figure 2.37 Waterfowl Survey Routes in the Churchill River Diversion Area, 1988

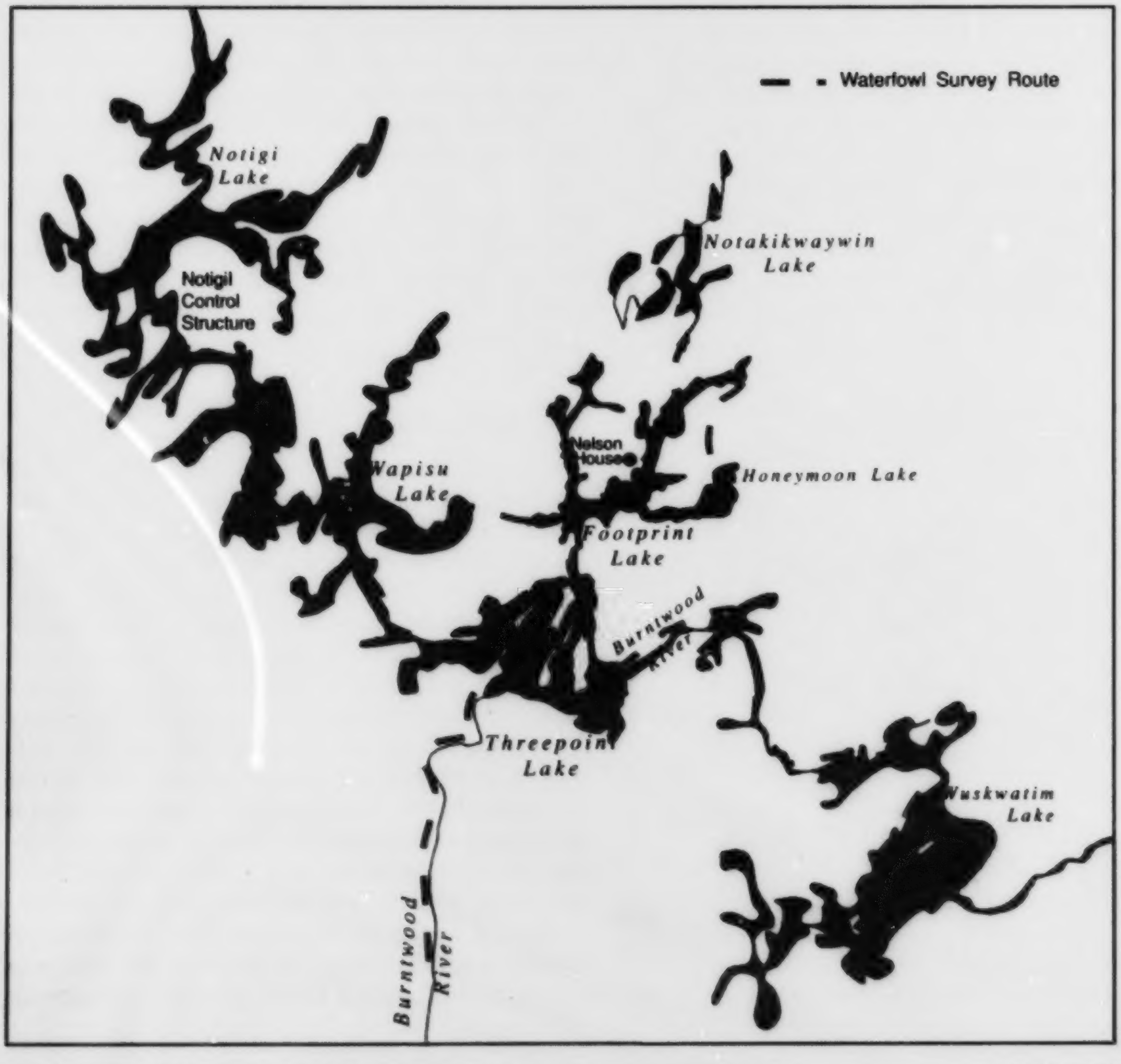

Waterfowl Survey Route
Notigi Lake
Notigil Control Structure
Notakikwaywin Lake
Nelson House
Honeymoon Lake
Wapisu Lake
Footprint Lake
Burntwood River
Threepoint Lake
Wuskwatim Lake
Burntwood River

Figure 2.38 *Numbers (N) and Densities[1] (D) of Waterfowl Observed in 1988 in the Churchill River Diversion Area*

	Sept 1, 1988		Sept 9, 1988		Sept 26, 1988	
Dabbling Ducks	N	D	N	D	N	D
Wapisu Lake	0	0.00	25	0.65	10	0.17
Rat River	4	0.20	30	1.50	0	0.00
Burntwood River (upstream)	5	0.28	4	0.23	6	0.34
Threepoint Lake	0	0.00	0	0.00	0	0.00
Burntwood River (downstream)	1	0.03	25	0.78	0	0.00
Wuskwatim Lake	0	0.00	0	0.00	1	0.02
Honeymoon Lake	2	0.30	22	2.51	3	0.34
Notakikwaywin Lake	N.S.	N.S.	N.S.	N.S.	35	2.47
Diving Ducks	N	D	N	D	N	D
Wapisu Lake	1	0.02	2	0.05	2	0.03
Rat River	0	0.00	14	0.70	0	0.00
Burntwood River (upstream)	0	0.00	12	0.68	0	0.00
Threepoint Lake	0	0.00	0	0.00	1	0.06
Burntwood River (downstream)	0	0.00	1	0.03	0	0.00
Wuskwatim Lake	20	0.58	5	0.12	5	0.12
Honeymoon Lake	7	1.04	1	0.11	2	0.23
Notakikwaywin Lake	N.S.	N.S.	N.S.	N.S.	27	1.91
Total Ducks[2]	N	D	N	D	N	D
Wapisu Lake	1	0.02	27	0.70	12	0.20
Rat River	4	0.20	44	2.20	0	0.00
Burntwood River (upstream)	5	0.28	16	0.91	6	0.34
Threepoint Lake	5	0.55	0	0.00	1	0.06
Burntwood River (downstream)	1	0.03	26	0.81	0	0.00
Wuskwatim Lake	20	0.58	5	0.12	6	0.14
Honeymoon Lake	9	1.33	23	2.63	5	0.57
Notakikwaywin Lake	N.S.	N.S.	N.S.	N.S.	62	4.38
Canada Geese	N	D	N	D	N	D
Wapisu Lake	0	0.00	0	0.00	0	0.00
Rat River	8	0.40	2	0.10	0	0.00
Burntwood River (upstream)	0	0.00	0	0.00	0	0.00
Threepoint Lake	0	0.00	0	0.00	0	0.00
Burntwood River (downstrem)	0	0.00	0	0.00	0	0.00
Wuskwatim Lake	0	0.00	75	1.74	0	0.00
Honeymoon Lake	0	0.00	0	0.00	0	0.00
Notakikwaywin Lake	N.S.	N.S.	N.S.	N.S.	0	0.00

---

[1] Densities are birds per kilometer based on survey lengths as follows: 181.6 km (Sept 1, 1986); 169.1 km (Sept 9, 1986); and 196.4 km (Sept 26, 1986).

[2] Total ducks includes diving ducks, dabbling ducks, and unidentified ducks.

N.S. = not surveyed

X = highest density by area

Figure 2.39 Numbers of Waterfowl Observed in 1973 in the Churchill River Diversion Area

Dabbling Ducks	Sept 7, 1973	Sept 26, 1973
Wapisu Lake	414	46
Rat River	200	87
Threepoint Lake	15	377
Burntwood River (downstream)	57	502
Wuskwatim Lake	72	944
Diving Ducks		
Wapisu Lake	12	22
Rat River	10	0
Threepoint Lake	20	31
Burntwood River (downstream)	5	0
Wuskwatim Lake	265	169
Total Ducks[1]		
Wapisu Lake	426	95
Rat River	235	87
Threepoint Lake	35	408
Burntwood River (downstream)	97	502
Wuskwatim Lake	388	1127
Canada Geese		
Wapisu Lake	0	0
Rat River	90	20
Threepoint Lake	6	90
Burntwood River (downstream)	0	0
Wuskwatim Lake	12	0

[1] Total ducks includes diving ducks, dabbling ducks, and unidentified ducks.

N.B. Densities are not shown because length of shorelines surveyed are not available.

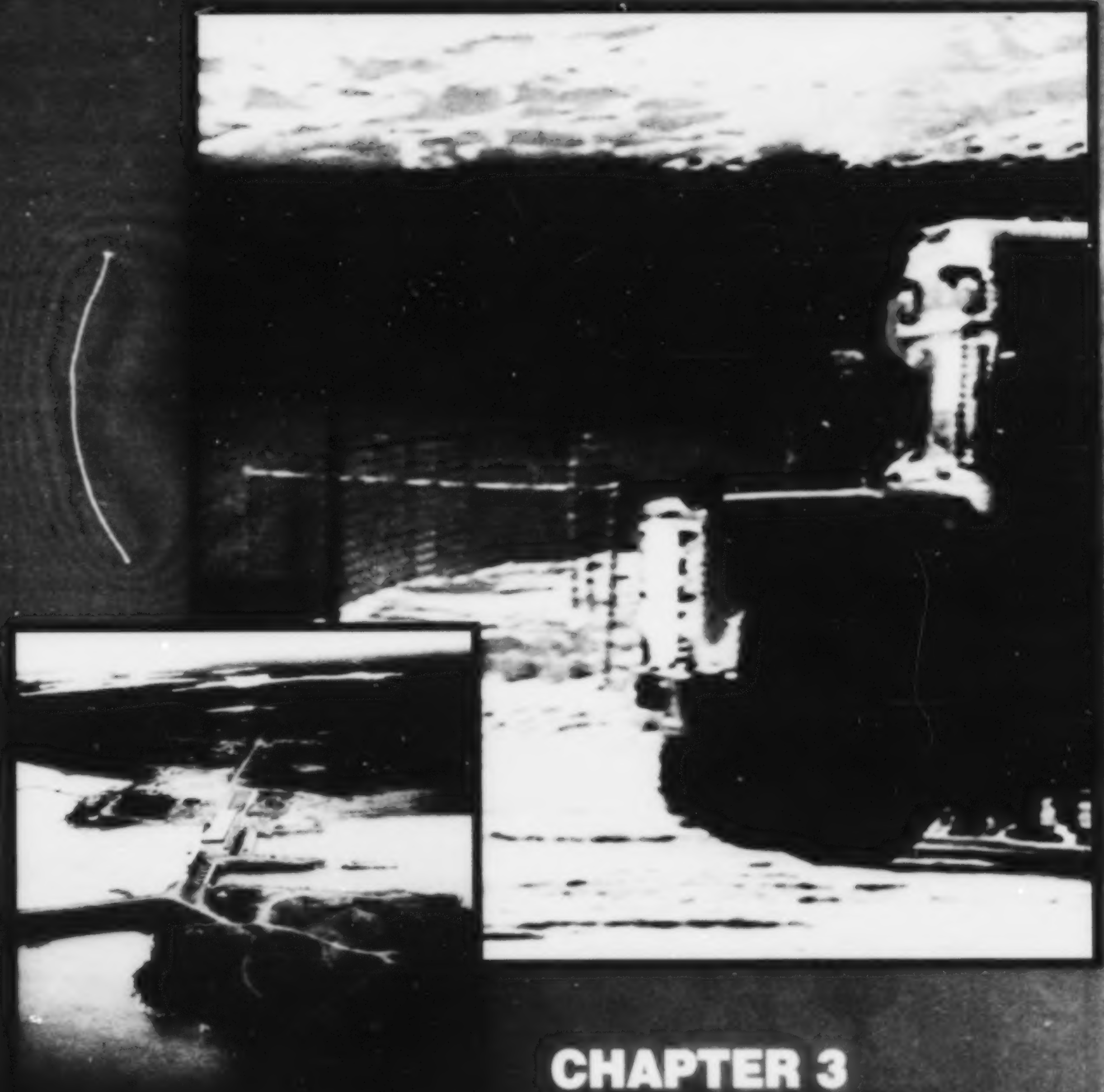
Comparison of the 1973 and 1988 data suggest that dabbling ducks declined by 97%, diving ducks declined by 89%, and Canada geese declined by 57%. It is risky, however, to draw broad conclusions about waterfowl numbers on the basis of the 1973 and 1988 surveys, because both surveys provide only a limited number of "point-in-time" counts. Furthermore, large between-year changes are not uncommon in waterfowl counts derived from aerial surveys. In addition, the small numbers of diving ducks and Canada geese observed in both surveys make it difficult to state, definitively, that a decline has occurred in all survey areas.

Two possible causes for the apparent change in dabbling duck use of the area were considered: 1) changes in regional populations; and 2) modifications to the local physical environment and waterfowl habitat. The only data on regional populations are the annual breeding pair surveys conducted by the U.S. Fish and Wildlife Service (USF & WS) in northern Manitoba. These data provide adjusted population estimates for ducks and serve as general indicators of population size and trends. These data estimate the size of breeding populations; they do not indicate the size of fall migrating flocks.

Data from Stratum 24, the USF & WS region, which most closely approximate the FEMP study area, were reviewed for the periods 1964 - 1975 and 1977 - 1988. When the 12-year means for the two periods were compared, the numbers of dabbling ducks were marginally higher (0.2%) in the latter period. However, large year-to-year fluctuations occurred during these periods; thus, the means on which these changes were based would vary somewhat as individual year counts were added or subtracted. The apparent reduction in the dabbling duck use of the diversion area does not appear to be a reflection of a long-term decline in regional populations as represented by the Stratum 24 counts, since no such trends were evident in the stratum data.

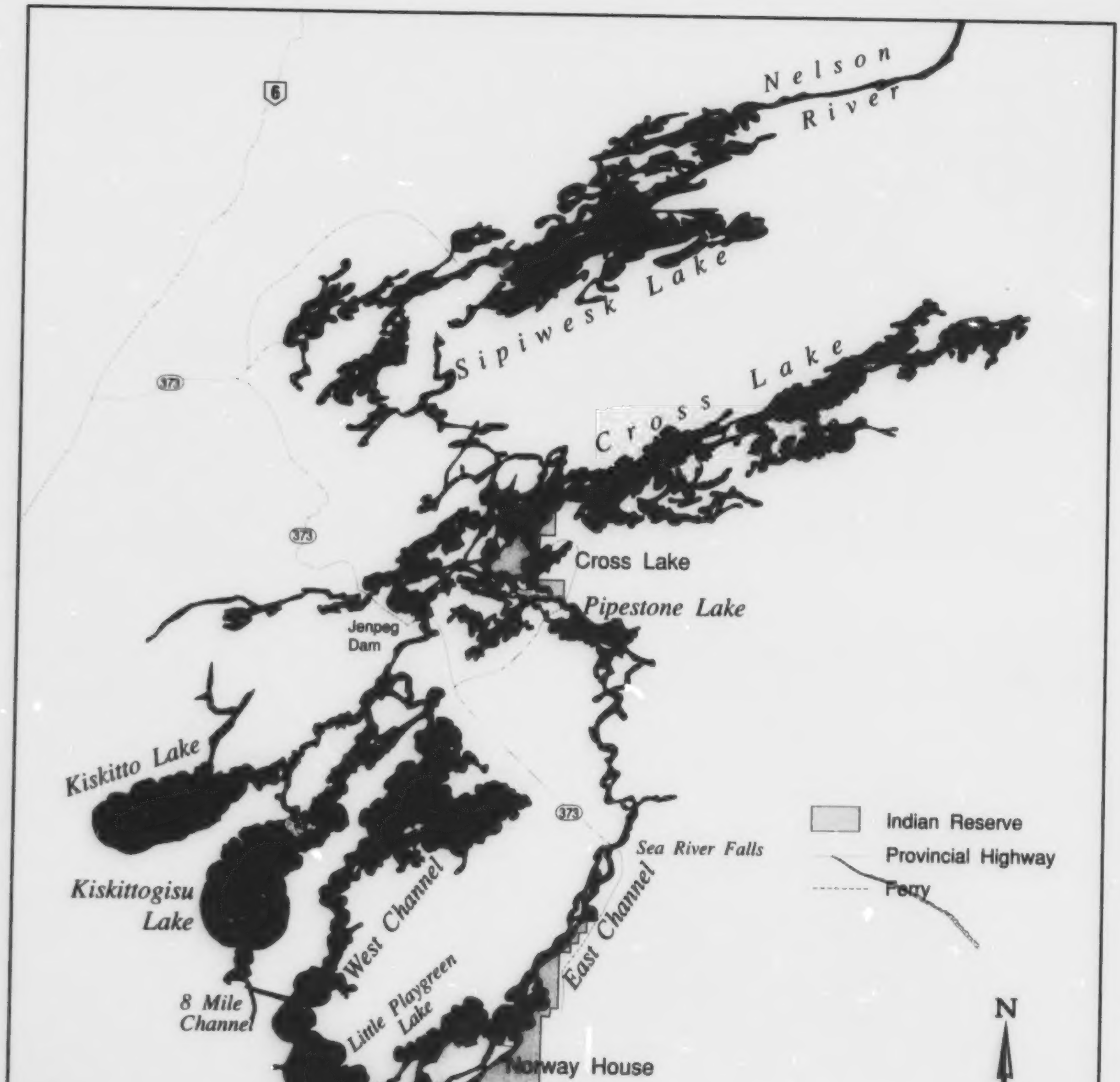
Modifications to the local physical environment and waterfowl habitat was the second possible cause considered for the apparent decrease in dabbling ducks. As noted previously in this chapter, the extensive flooding along the diversion route greatly altered the shoreline characteristics (e.g. increased debris and standing dead trees, etc.); this alteration has created poor quality habitat for waterfowl, rendering these areas less attractive for dabbling ducks and (to a lesser extent) for diving ducks.

In summary, low numbers of ducks and Canada geese were observed in September 1988 in the Churchill River diversion area. Temporal and spatial data, as well as the current data, were too limited to estimate changes in the levels of waterfowl use of this area with any degree of confidence. The data suggest, however, that there may have been a decline in the dabbling duck use of this area following diversion.



CHAPTER 3

THE OUTLET LAKES AREA

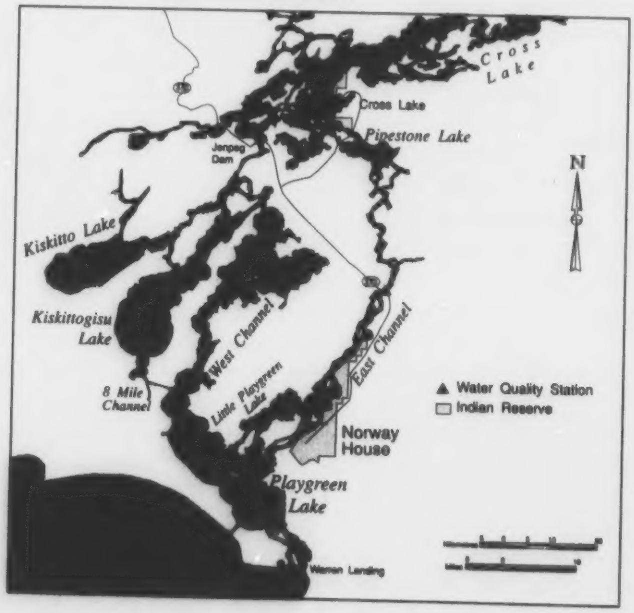

6
Nelson River
Sipiwesk Lake
373
Cross Lake
373
Cross Lake
Pipestone Lake
Jenpeg Dam
Kiskitto Lake
373
Kiskittogisu Lake
West Channel
Sea River Falls
East Channel
8 Mile Channel
Little Playgreen Lake
Norway House
Jack River
Playgreen Lake
Warren Landing
Indian Reserve
Provincial Highway
Ferry
N
Kilometres 5 0 5 10 20 30
Miles 5 0 10 20

MORPHOLOGY AND SEDIMENT REGIMES

FEMP investigations of the morphology and sediment regimes in the Outlet Lakes area were limited to: 1) a review of the existing literature on the morphology of this area, most of which was the product of work conducted by or for Manitoba Hydro; 2) an assessment of future required morphological study; and 3) the collection of data on suspended sediment, as part of the FEMP water quality program, at two sites, the Nelson River below Sea River Falls and Jack River (Fig. 3.1). (Cross Lake was not sampled under FEMP because it was one of the six lakes along the Nelson, Rat, and Burntwood rivers that were being extensively monitored by the Manitoba Department of Natural Resources, concurrent with FEMP.)

Regular monitoring of the 8-Mile and 2-Mile channels, located in relatively low-lying, flat areas of peat and clay, indicated apparently substantial erosion during the first two years of operation, but much less since. Near the entrance to 2-Mile Channel, the protective beach found elsewhere on the north shore of Lake Winnipeg is missing and rates of bank retreat are much higher. Since the erosion process is closely related to the occurrence of severe storms, it is episodic. In Playgreen Lake, comparative analysis of air photos, dating back to 1946, for 8 sites showed highly variable bank retreat rates. No changes in shore erosion rates attributable to Lake Winnipeg regulation could be detected.

Figure 3.1 FEMP Water Quality Sites in the Outlet Lakes Area



Future morphological and related studies that should be considered for the Outlet Lakes area include: 1) documentation of the large erosion rates observed at the entrance to the 2-Mile Channel and an assessment of their long-term effects; 2) an investigation of the sedimentation in Playgreen Lake off the mouth of 2-Mile Channel; and 3) an examination of the morphological evolution of the lakes in this area, especially Cross and Sipiwesk lakes.

Data on turbidity, total dissolved solids (TDS), non-filterable residue (NFR) and colour for the two sites in the Outlet Lakes area are shown in Fig. 3.2. As was the case for all the sites sampled under the FEMP water quality project, the mean turbidity values for these 2 sites exceeded the Canadian Water Quality Guideline for turbidity levels in drinking water of 5 NTU. Statistical comparison of current conditions with pre-development conditions was not possible for either site because of the lack

Figure 3.2 Turbidity, Total Dissolved Solids, Non-Filterable Residue, and Colour for the Outlet Lakes Area, 1987 - 1989

Variable	Type	Units	Mean	SD	Max.	Min.
Nelson River below Sea River Falls						
Turbidity	field	NTU	10.+	3.	16.+	6.+
	lab	NTU	8.+	3.	13.+	4.
TDS		mg·L⁻¹	163.	19.	189.	124.
NFR	total	mg·L⁻¹	6.	3.	10.	3.
	fixed	mg·L⁻¹	5.	3.	10.	2.
Colour	true	relative	9.	4.	20.+	3.
Jack River (West Channel)						
Turbidity	field	NTU	10.+	6.	34.+	5.
	lab	NTU	9.+	5.	26.+	3.
TDS		mg·L⁻¹	165.	16.	185.	122.
NFR	total	mg·L⁻¹	7.	4.	20.	2.
	fixed	mg·L⁻¹	5.	4.	17.	1.
Colour	true	relative	8.	4.	15.	3.

Footnotes

+ Exceeds limit for drinking water
Exceedences in the "Max." column indicates occasional exceedences.

of sufficient pre-development data. However, an analysis by the Manitoba Department of Environment of the more extensive database for their nearby site on the Nelson River near Norway House showed a small increase in turbidity from the 1972 - 1976 period to the 1976 - 1984 period.

WATER QUALITY

Introduction

A three-year water quality study, from January 1987 to October 1989, of 61 physical and chemical water quality variables was conducted at 11 sites in the FEMP study area; 2 of these 11 sites were located in the Outlet Lakes area. This section presents the results of the water quality study for this area, as follows: 1) listings of those water quality variables whose values, from 1987 to 1989, exceeded the Canadian Water Quality Guidelines; 2) comparisons of current water quality conditions to historical conditions, to the extent that the data exists; 3) relationships, if any, between the water quality variables and river discharges; 4) differences in water quality conditions between the ice-free and ice-cover seasons; and 5) results of the limited bacteriological assessment of the recreational waters in and around the NFC communities.

Canadian Water Quality Guidelines, established in 1987, were used as a means for assessing the water quality in the FEMP study area. Major uses of water for which Guidelines have been developed include drinking water, recreational use and the protection of aquatic life. Variations in environmental conditions across Canada will affect water quality in different ways; hence, many of the Guidelines may need to be modified according to these local conditions. The use of the Guidelines for assessing adverse effects in the FEMP study area is limited in that they have not been established for all variables, they are not based on site-specific cause and effect studies in northern Manitoba, and they do not take into account the effect of cumulative stresses caused when the values of two or more water quality variables simultaneously exceed the guideline values. They are thus a suggestive, rather than a definitive, basis for assessing adverse effects in the FEMP study area.

Nelson River Below Sea River Falls

A few variables at this site (Figs. 3.2 + 3.3) exceeded the Canadian Water Quality Guidelines; these same variables commonly exceeded the Guidelines at most of the FEMP water quality sites, including those on the unregulated rivers. Mean levels of turbidity, extractable aluminum (Al) and total copper (Cu) exceeded the Guidelines. While extractable iron (Fe) concentrations

Figure 3.3 Water Quality Variables Which Exceeded the Canadian Guidelines in the Outlet Lakes Area, 1987 - 1989

Variable	Type	Units	Mean	SD	Max.	Min.
Nelson River below Sea River Falls						
Al	extractable	mg·L^{-1}	0.181^{++}	0.094	0.385^{++}	<0.100
Cu	total	mg·L^{-1}	0.0047^{++}	0.0054	0.0208^{++}	0.0011
Fe	extractable	mg·L^{-1}	0.197	0.072	0.365$^{+,++}$	0.087
Mn	extractable	mg·L^{-1}	0.016	0.012	0.067^{+}	0.005
Jack River (West Channel)						
Al	extractable	mg·L^{-1}	0.176^{++}	0.126	0.442^{++}	<0.100
Cu	total	mg·L^{-1}	0.0034^{++}	0.0038	0.0159^{++}	0.0011
Fe	extractable	mg·L^{-1}	0.187	0.106	0.457$^{+,++}$	0.070
Pb	total	mg·L^{-1}	0.0007	0.0006	0.0027^{++}	<0.0007

Footnotes

$^{+}$ Exceeds limit for drinking water

$^{++}$ Exceeds limit for protection of aquatic life

Exceedences in the "Max." column indicates occasional exceedences.

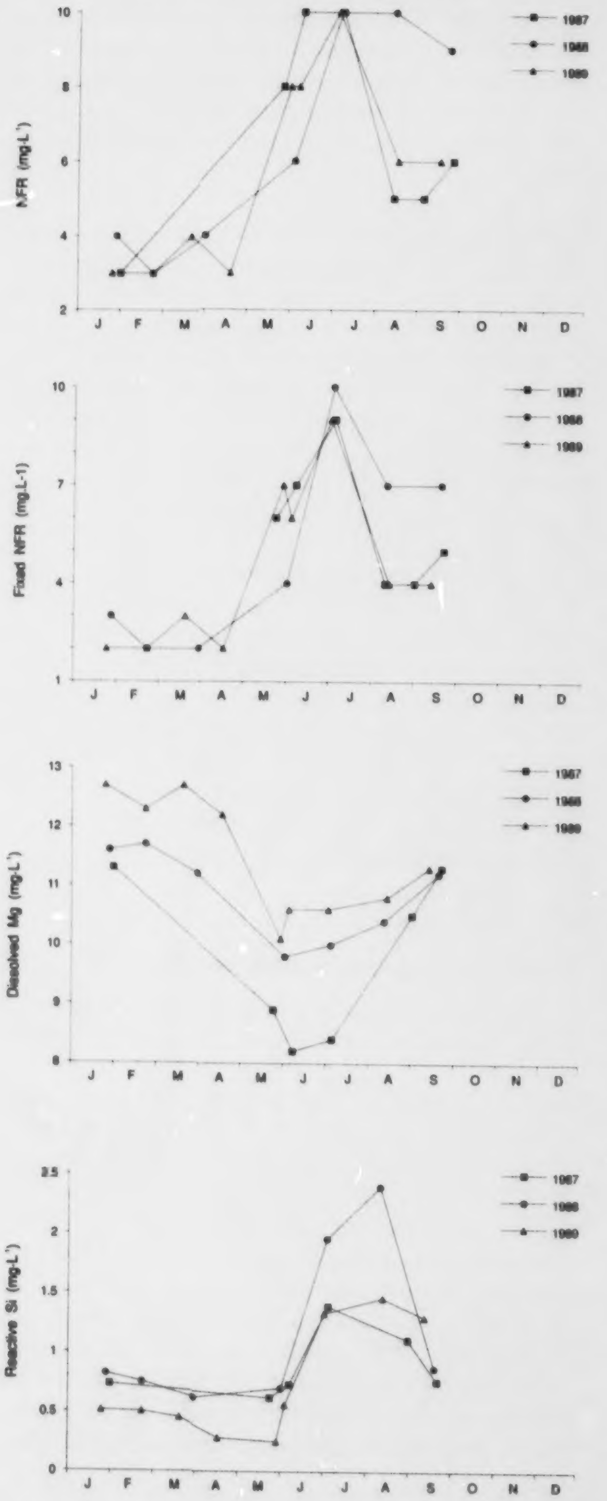
occasionally exceeded the Guidelines, they were lower at this site than for those along the Churchill River Diversion and in the natural rivers. Fe concentrations above the GUidelines were characteristic of natural rivers in northern Manitoba, occurring at all of the sites samples in this study. Extractable manganese (Mn) concentrations at this site also occasionally exceeded the Guidelines.

Insufficient pre-development data for this site prevented a quantitative analysis of water quality changes from pre-development to post-development conditions. The only way of assessing the impacts of the LWCN project on the water quality at the Sea River Falls site would be to use data from an acceptable surrogate site. The Nelson River at Norway House is the only possible choice for this purpose as it was routinely sampled from 1972 to 1974; however, it would first be necessary to demonstrate that water quality at the two sites should have been the same prior to development. This validation would require some field reconnaissance as well as consultation with individuals knowledgable in the recent history of development (i.e. past 25 years) along this reach of the Nelson River.

A number of water quality variables were correlated with Nelson River discharge at this site during the 1987 - 1989 study period. Negative correlates included most major ions, alkalinity and conductivity, while positive correlates included turbidity, non-filterable residue (NFR) and extractable Fe. Most of the significant water quality - discharge relationships at this site were strong enough to offer promise in impact prediction and management. The sparse pre-development water quality data precluded an analysis of changes in discharge relationships since the LWCN project.

Seasonal differences, for the 1987 - 1989 study period at this site, were limited, with only 4 variables showing any seasonal variation (Fig. 3.4). Total and fixed NFR and reactive silicon (Si) were lower under ice-cover while magnesium (Mg) was higher. While 3 of these variables were correlated with discharge, fluctuations in discharge fail to account for the seasonal patterns observed at this site. The pre-development data set was judged inadequate for an assessment of seasonal patterns for that period.

Figure 3.4 ***Seasonal Water Quality Trends for Selected Water Quality Variables in the Nelson River below Sea River Falls***



Jack River

The water quality variables at the Jack River site that exceeded the Canadian Water Quality Guidelines were similar to those at the Sea River Falls site. Mean levels of turbidity, extractable Al, and total Cu exceeded the Guidelines, while levels of extractable Fe and total lead (Pb) occasionally exceeded these Guidelines. (Figs. 3.2 + 3.3)

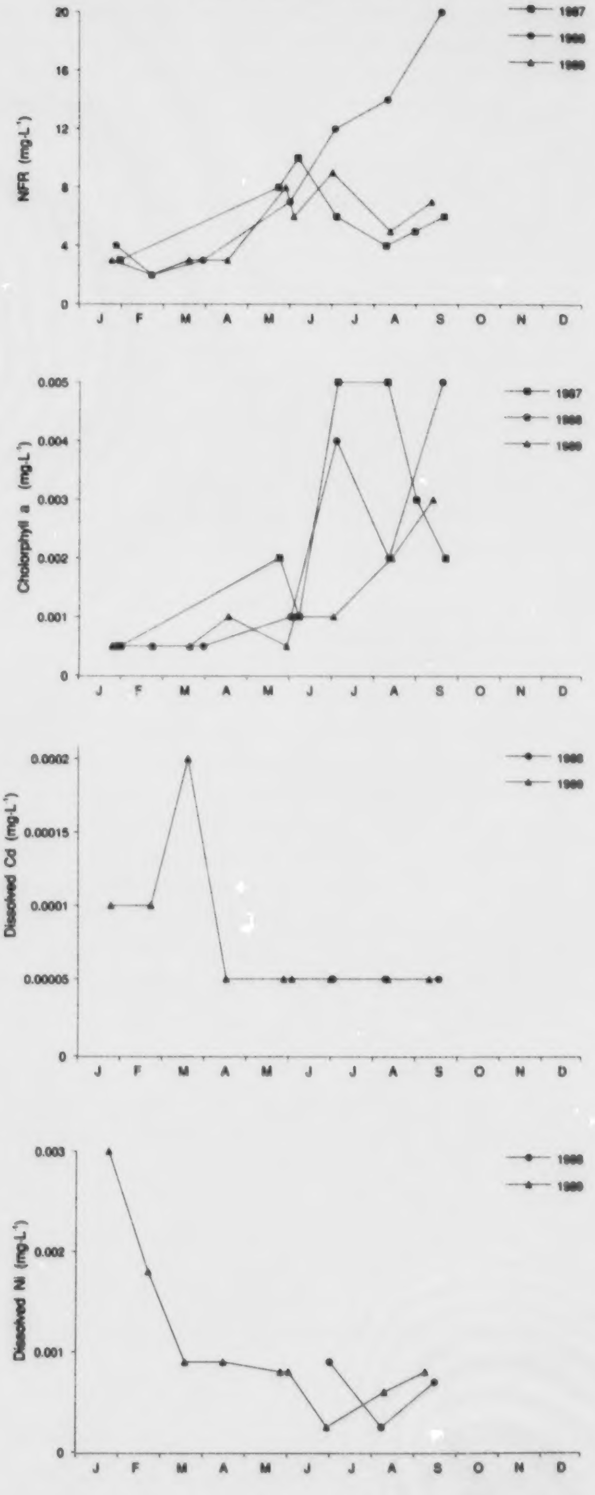
There are no pre-development water quality data for this site and consequently no means of directly determining to what extent, if any, the water quality has changed since the LWCN project. As suggested for the Sea River Falls site, it may be possible to use pre-development data for another upstream site as a surrogate. The only upstream site which was adequately sampled prior to development is the Nelson River at Warren Landing, which has been sampled since 1969. Verification of this site as a suitable surrogate would be required.

There were few clear differences in water quality between the ice-free and ice-cover seasons during the 1987 - 1989 FEMP study. NFR was lower under ice-cover, as was chlorophyll a, while dissolved cadmium (Cd) and nickel (Ni) concentrations were higher under ice-cover (Fig. 3.5). The lower chlorophyll a under ice was consistent with the trend at other sites. The lower NFR and higher Cd and Ni under ice could be a product of lower winter flows, but this cannot be confirmed due to the lack of discharge data for this site.

Bacteriological Assessment

A bacteriological assessment of the recreational waters in the Norway House and Cross Lake areas was conducted in 1987. Seasonal studies were conducted from May to September at 8 sites at Norway House and 5 sites at Cross Lake; in addition, intensive studies were conducted in the vicinity of the water treatment plants in August. The geometric mean fecal coliform bacteria for the seasonal studies ranged between 3 and 39 per 100 mL at Norway House and 6 and 44 at Cross Lake. The geometric means for the intensive study were 9 per 100 mL for both Cross Lake and Norway House. Comparison of the results of the intensive studies to the Canadian Water Quality Guidelines of 200 bacteria per 100 mL indicates that the bacteriological water quality at these sites were generally acceptable for recreational water

Figure 3.5 ***Seasonal Water Quality Trends for Selected Water Quality Variables in the Jack River near Norway House***



uses. Limited sampling frequency for the seasonal studies precludes direct comparisons of their results to this guideline.

MERCURY

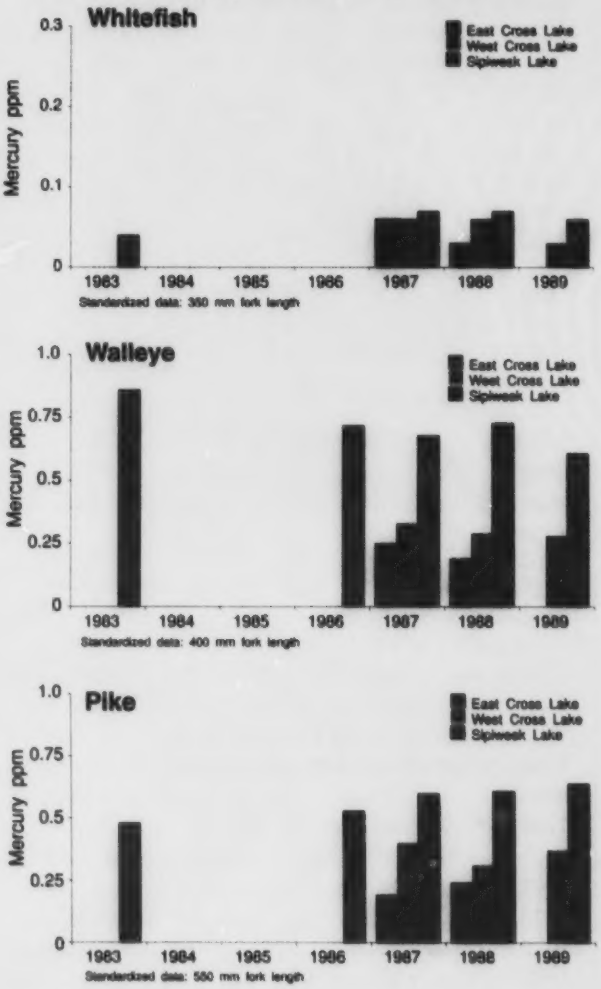
The FEMP mercury program focused on the Churchill River Diversion (CRD) route since this was the region within the FEMP study area that has experienced the most severe mercury problem. The basic processes that govern the production of methyl mercury, the expected longevity of elevated mercury levels in fish, and possible mitigative measures were discussed in chapter 2. In this chapter, only mercury issues specific to the Outlet Lakes area are discussed, namely: 1) current mercury levels in fish in Cross and Sipiwesk lakes; 2) current mercury levels in residents of Cross Lake and Norway House; and 3) the expected future mercury regime for Cross and Sipiwesk lakes.

Mercury levels in fish in Cross and Sipiwesk lakes were sampled by the Manitoba Department of Natural Resources (Fig. 3.6). Mercury levels in whitefish, walleye and pike from Cross Lake were all below the Canadian guideline of 0.5 ppm. In Sipiwesk Lake, mercury levels in whitefish were also below the 0.5 ppm level, while mercury levels in walleye and pike were generally between 0.5 ppm and 1.0 ppm.

Mercury levels in residents of Cross Lake and Norway House were monitored by Health and Welfare Canada (Fig. 3.7). Of the approximately 20% of the population of Cross Lake tested for mercury in 1989/90, 98% had values in the 0-19 ppb range, which is considered to be the "normal" range; all of the remaining values were in the range of 20-50 ppb. For women of child-bearing age who were tested, 98% had values in the 0-19 ppb range.

Of the approximately 24% of the population of Norway House tested in 1988/89, 97% had values in the range of 0-19 ppb; all of the remaining values were in the 20-50 ppb range. For women of childbearing age, almost 98% were in the 0-19 ppb range. Unlike South Indian Lake and Nelson House, there were never any mercury levels in the tested populations of Cross Lake and Norway House that exceeded 99 ppb.

Figure 3.6 Standardized Mean Muscle Mercury Concentrations for Fish in Cross and Sipiwesk Lakes, 1983 - 1989



The residents of Cross Lake have expressed a concern that the new Cross Lake weir, which will raise lake levels during the open-water season to more closely approximate pre-development levels, will cause a rise in mercury levels in fish. However, unlike the CRD, there will be no extensive backflooding of bog or forest terrain associated with the weir, because the rise in water level is expected to be contained within the natural basin of Cross Lake. It is therefore unlikely that the resulting higher water level on Cross Lake will cause any long-term increase in fish mercury levels.

Another important factor in assessing the potential of the Cross Lake weir to cause increased mercury levels in fish is the fact that the majority of the shoreline of Cross Lake is bedrock controlled, which greatly limits the potential for revegetation of the drawdown zone during

Figure 3.7 Mercury Levels in Residents of Cross Lake and Norway House

Mercury Levels in Residents of Cross Lake

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1977	96	79	17	0
1978	1	1	0	0
1979	0	0	0	0
1980	70	58	12	0
1981	225	207	18	0
1982	296	275	21	0
1983	7	7	0	0
1984	200	192	8	0
1985	93	90	3	0
1989-90	494	484	10	0

1989-90 Groups	*Sample Number*	*0-19 ppb*	*20-50 ppb*	*50-80 ppb*
Men	92	87	5	0
Women:				
12-45 yrs	136	133	3	0
over 45 yrs	58	56	2	0
Children:				
1-4 yrs	33	33	0	0
5-12 yrs	175	175	0	0

Mercury Levels in Residents of Norway House

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1977	144	127	17	0
1978	81	75	6	0
1979	0	0	0	0
1980	66	59	7	0
1981	107	99	8	0
1982	127	126	1	0
1983	54	54	0	0
1984	221	212	9	0
1989-90	775	752	23	0

1989-90 Groups	*Sample Number*	*0-19 ppb*	*20-50 ppb*	*50-80 ppb*
Men	326	318	8	0
Women:				
12-45 yrs	275	269	6	0
over 45 yrs	94	85	9	0
Children:				
1-4 yrs	46	46	0	0
5-12 yrs	34	34	0	0

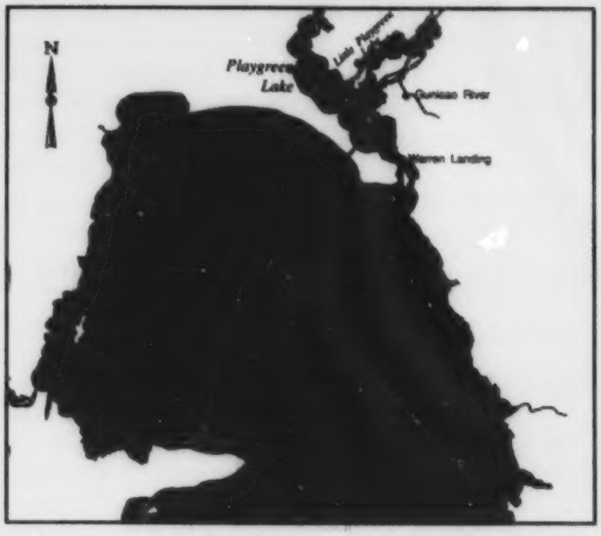
periods of low water. Cross Lake levels have fluctuated substantially since the Jenpeg Generating Station began operating in 1976, by as much as 3 m in a single year, yet mercury levels in pike and walleye from Cross Lake are not higher than the average for lakes in northern Manitoba (0.3-0.4$\mu g \cdot g^{-1}$). Any vegetation which became established in the drawdown zone apparently was not of sufficient quantity to cause a substantial elevation in net microbial methylation when it was flooded. Similar conditions would likely prevail after the weir is constructed, in which case an increase in fish mercury levels would not occur. This assessment should be confirmed, however, by mercury monitoring for at least 2 years after the weir is constructed.

The situation in Cross Lake contrasts with that of Sipiwesk Lake where only 5% of the post-impoundment shoreline is bedrock controlled, with the remainder composed of flooded forest and wetland soils which provide excellent substrate for growth of vegetation during periods of low water. In the drawdown zone of Sipiwesk Lake, recolonization by grasses and other fast growing vegetation occurs. These materials are flushed into the lake during periods of high water, becoming available to the methylating bacteria. A continuous source of fresh organic matter such as this can be expected to maintain methyl mercury production at a high level longer than would be the case otherwise. This appears to be the case in Sipiwesk Lake, where the specific methylation rate in the flooded zone was at the high end of the expected range in 1987 and where mercury levels in fish were greater than the average for northern Manitoba lakes.

PLAYGREEN LAKE / LAKE WINNIPEG WHITEFISH STOCK GENETICS

It has long been supposed that there are movements of whitefish between Playgreen Lake and the north end of Lake Winnipeg. For example, a tagging program in 1973 of a large number of whitefish at Warren Landing found that fish were recaptured in both Lake Winnipeg and in Playgreen Lake. Changes in the geographic and/or temporal distribution of flow between Lake Winnipeg and Playgreen Lake might be expected to disrupt migration patterns between the two lakes, and possibly also the genetic structure of stocks in the area. Since the construction of 2-Mile Channel (2MC) in 1975 and the regulation of Lake Winnipeg, the geographic and seasonal distribution of flows through the Playgreen Lake area have been

Figure 3.8 Gill Net Sites for Playgreen Lake/Lake Winnipeg Stock Genetics Study



altered. For example, a higher proportion of flow now proceeds by the west channel of the Nelson River and a significant proportion of the flow now leaves Lake Winnipeg via 2MC, especially during periods of low water levels on Lake Winnipeg.

Since these changes in the water regime, fishermen on Playgreen Lake have claimed that the spatial distributions and seasonal movements of separate stocks of whitefish in the Lake Winnipeg and Playgreen Lake areas have changed. In response to these claims, a FEMP investigation was initiated of the genetic structuring of the population of whitefish in Playgreen Lake and in the northern end of Lake Winnipeg. The objective of this study was to compare the genetic stock of the whitefish populations in 1989 to that of 1975 to determine if a significant change had occurred.

A fish stock is by definition (Larkin 1972) a population which shares a common environment and gene pool. This definition implies a degree of reproductive isolation between various stocks of a particular fish species in a particular area; this reproductive isolation will generally be expected to result in genetic differences between stocks, which will tend to accumulate due to random genetic drift and/or selection. The genetic differences expected among various stocks of fish and the environmental differences expected in their habitats have allowed the development of various methods to identify and differentiate stocks; one of these methods, starch gel electrophoresis of isozymes, was used in the FEMP study.

Whitefish sampling was conducted in late October 1989, at a time close to that when whitefish spawning was expected to occur and hence a time when stocks would be expected to have segregated themselves into reproductively isolated units. Samples of approximately fifty mature whitefish were collected by gill netting from six different sites in northern Lake Winnipeg and Playgreen Lake (Fig. 3.8); four of these sites had also been sampled in 1975.

The major finding of the FEMP study was that there were at least two different stocks of whitefish in the northern Lake Winnipeg/ Playgreen Lake area. One stock utilized sites in the north basin of Lake Winnipeg for spawning (Grand Rapids and Big Black River) and a second stock utilized Little Playgreen Lake for spawning. The genetic differences observed in this study were likely attributable to both an innate homing of whitefish to natal spawning grounds and a degree of geographic isolation of stocks by distance. These genetic similarities and differences were also found in the 1975 study. It, thus, appears that these genetic differences were stable over time and that the genetic structure of the stocks has not changed since the regulation of Lake Winnipeg. This conclusion, however, is tentative and preliminary for a number of reasons.

While genetic differences indicate distinct stocks, genetic similarities do not prove identity. Thus, there may be more than two genetic stocks present in the northern Lake Winnipeg/Playgreen Lake area. This uncertainty is in part due to the need for more refined genetic models which would enable the interpretation of a more extensive data set than that which was analyzed in the FEMP study.

This uncertainty may be resolved by a planned analyses of morphological data on both the 1975 and 1989 samples. Morphological differences can exist between stocks which are not based solely on genetic differences, but are at least in part environmentally induced; this is especially true of some fish, such as whitefish, in which extreme morphological variations are possible. (This characteristic of whitefish formed the basis for a study of whitefish below Missi Falls, discussed in chapter 2.)

The morphological results may allow for the identification of additional stocks not ascertained by genetic analysis. In fact, it is already known that there were more than two genetic stocks of lake whitefish in the northern Lake Winnipeg/Playgreen Lake area in 1975; Kristofferson and Clayton (1990) found that the Grand Rapids, Big Black River, and Little Playgreen spawning stocks were separable on the basis of morphological characteristics. Further morphological study may result in the discrimination of additional stocks in the post-development samples.

FISH MIGRATIONS THROUGH 2-MILE CHANNEL, PLAYGREEN LAKE

In a complementary study to the Playgreen Lake/Lake Winnipeg whitefish stock genetics study, a FEMP study was undertaken to assess the use of 2-Mile Channel (2MC) as a fish migration corridor between Playgreen Lake and Lake Winnipeg. In the early summer (late June) and fall (mid-October) of 1989, a dual-beam echosounder was employed in fixed and mobile configurations in the 2MC area of Playgreen Lake to evaluate its utilization by migrating fish. Gill nets were set in the area of the 2MC outlet during the early summer sampling. Due to problems with software for analysis of the echosounder digitized data, echosounder information has not yet been statistically analyzed. A final project report should be available in 1992.

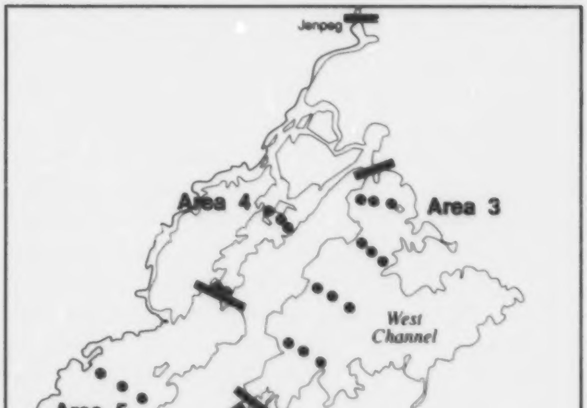
BENTHIC INVERTEBRATES

The water regime of Playgreen and Kiskittogisu lakes changed after the regulation of Lake Winnipeg. In particular, 2-Mile Channel (2MC) now contributes most of the flow to Playgreen Lake during periods of low water levels; it also introduces material that has eroded from the north shore of Lake Winnipeg into the south basin of Playgreen Lake. 8-Mile Channel (8MC), connecting the southern portions of Playgreen and Kiskittogisu lakes, enables Kiskittogisu Lake to contribute approximately 30% of the flow through the West Channel. A FEMP study was conducted to examine the status of the benthic invertebrates in Playgreen and Kiskittogisu lakes following these changes in the water regime.

Thirty-three stations were sampled in Playgreen Lake, in July 1987 and 1989, with an approximately even distribution among three areas of the lake (Fig. 3.9). Twelve stations were sampled in Kiskittogisu Lake, in July 1989, with an approximately even distribution between its two areas. Sites were located in critical areas of the lakes (e.g. just north of 8-Mile Channel) and at locations close to sites that were sampled in a 1971 benthic invertebrate survey. Three samples were taken at each site, accompanied by a Secchi disc reading, a temperature profile, and a qualitative description of the sediments, including particle size and sediment compactness. Water samples were also taken from selected stations for routine chemical analysis during the 1987 Playgreen Lake survey.

The mean standing stock in the western section of the south basin of Playgreen Lake, the area located in the sediment plume from 2MC, was more productive in 1987 than either of the central or eastern sections (13100 versus approximately 10600 organisms m^{-2}). A similar

Figure 3.9 Benthic Invertebrate Sampling Sites in the Outlet Lakes Area, 1987 and 1989



but less pronounced relationship was observed in 1989. The region north of 8MC showed no significant differences between west, central and east sections in either of the years of survey. The mean standing stock for the north basin of Playgreen Lake was less than in the south basin, especially in 1987.

While a north/south basin difference in mean standing stocks had existed in the pre-project survey conducted in 1971, this difference was intensified in 1987. In addition, the mean standing stocks were much lower for all parts of Playgreen Lake in 1971 than in either 1987 or 1989 (Fig. 3.10); this difference, however, might have been caused by methodological differences in the surveys. The lower numbers in 1989 in comparison to 1987 were probably the result of drought conditions. (Fig. 3.11)

Figure 3.10 Mean Standing Stock of Invertebrates in Playgreen and Kiskittogisu Lakes, 1971, 1987, and 1989

	Playgreen Areas			Kiskittogisu Areas	
Survey Years	1	2	3	4	5
1971	502	437	419	212	209
1987	11558 (1548)	8667 (1687)	4941 (419)	NS	NS
1989	4417 (1161)	3223 (499)	2654 (184)	2087 (191)	3496 (527)

N.B: units no·m^{-2} (±SE); NS = Not Sampled

In 1971, the most abundant taxon in each area of Playgreen Lake was Amphipoda, followed by Mollusca and Ephemeroptera (Fig. 3.12). Diptera and Oligochaeta appeared less frequently than expected, possibly because the sorting techniques missed smaller forms. In 1987, the basic order of the 1971 abundances still held, with Amphipoda generally the most abundant taxon in each area, followed by Mollusca, Diptera, and Ephemeroptera. In 1989, an abrupt change occurred in the abundance ranking of taxa within each area, primarily because of a major decrease in the number of Amphipoda, but also because the relative abundance of Ephemeroptera increased.

In Kiskittogisu Lake, the 1989 standing stock in the south basin, which receives direct inflow from 8MC was 68% higher than in the more remote northern basin; this was in contrast to 1971 when the mean standing stocks in the two areas were almost identical (Fig. 3.10). As was the case with Playgreen Lake, the mean standing stock recorded in 1971 was low. The order of abundance of individual taxa in the northern portion of the lake in 1971 was Mollusca, followed by Ephemeroptera and then Amphipoda. Diptera and Oligochaeta were rare. In 1989 this order changed to Ephemeroptera, followed by Diptera, Amphipoda, and Mollusca (Fig. 3.13). The order of abundance in the southern portion in 1971 was Ephemeroptera, followed by Amphipoda and then Mollusca; this changed in 1989 to Ephemeroptera, followed by Mollusca and then Diptera.

Figure 3.11 Mean Abundance of Taxa Found in the Regions South and North of the 8-Mile Channel in Playgreen Lake, 1987 and 1989

Year	Region	Diptera	Amphipoda	Olig.	Mollusca	Ephem.	Trich.	Misc.	Total
1987	South	1250 (341)	5073 (1001)	355 (171)	3993 (839)	423 (98)	171 (27)	250 (51)	11516 (1298)
	North	1023 (85)	1998 (293)	15 (8)	1341 (175)	405 (93)	35 (8)	16 (51)	4833 (335)
1989	South	1410 (757)	513 (242)	341 (117)	1261 (339)	576 (116)	23 (8)	26 (7)	4151 (827)
	North	360 (41)	165 (54)	27 (11)	1061 (190)	995 (110)	6 (3)	16 (5)	2631 (159)

N.B: units no·m^{-2} (±SE); South = sites 1-17; North = sites 18-33, Olig. = Oligochaeta;
Mollusca: ~80% Pelecypoda and ~20% Gastropoda; Ephem. = Ephemeroptera, Trich. = Trichoptera

Figure 3.12 Mean Standing Stock of Individual Taxa in Areas 1 - 3 of Playgreen Lake, 1971, 1987, and 1989

	Year	Diptera	Amphipoda	Olig.	Mollusca	Ephem.	Trich.	Misc.
Area1	1971	15	201	1	170	98	12	6
	1987	1603	5586	499	2989	437	199	245
		(499)	(1459)	(255)	(632)	(141)	(34)	(72)
	1989	1880	658	385	896	553	27	17
		(1163)	(361)	(172)	(168)	(152)	(11)	(6)
Area 2	1971	0	141	0	251	33	11	1
	1987	829	3053	70	3883	584	78	170
		(136)	(759)	(40)	(1391)	(130)	(28)	(52)
	1989	525	184	167	1298	1010	11	29
		(65)	(104)	(79)	(579)	(200)	(6)	(11)
Area 3	1971	22	238	1	117	34	41	3
	1987	976	2186	8	1469	253	41	8
		(95)	(333)	(3)	(209)	(54)	(9)	(5)
	1989	317	191	28	1299	793	7	19
		(28)	(71)	(15)	(208)	(76)	(3)	(6)

N.B: units no m^{2} (±SE); South = sites 1-17; North = sites 18-33, Olig. = Oligochaeta; Ephem. = Ephemeroptera, Trich. = Trichoptera

Figure 3.13 Mean Standing Stock of Individual Taxa in Areas 4 and 5 of Kiskittogisu Lake, 1971 and 1989

	Year	Diptera	Amphipoda	Olig.	Mollusca	Ephem.	Trich.	Misc.
Area4	1971	8	49	2	85	55	0	7
	1989	502	330	49	259	916	0	32
		(118)	(183)	(36)	(129)	(124)	(11)	(16)
Area 5	1971	8	68	0	36	97	0	0
	1989	431	139	135	1267	1503	4	16
		(89)	(114)	(65)	(232)	(350)	(5)	(13)

N.B: units no m^{2} (±SE); South = sites 1-17; North = sites 18-33, Olig. = Oligochaeta; Ephem. = Ephemeroptera, Trich. = Trichoptera

The south basin of Playgreen Lake was the most productive and diverse region sampled in 1971, 1987 and 1989, probably because of the stabilizing influence of the large mass of water in Lake Winnipeg. Within the south basin, invertebrate populations were generally higher along the plume of suspended material entering Playgreen Lake from 2MC than in other parts of the basin. This indicates an enhancement of the benthic populations by the augmented flow from this channel, possibly by the addition of particulate organic material. Because the plume of sediment probably contains organic material washed from the shore of Lake Winnipeg, it provides a source of sustenance for the benthic invertebrates.

The portion of Playgreen Lake that lies north of 8MC appears to have suffered a decrease in the standing stock of benthic invertebrates following construction of the diversion into Kiskittogisu Lake. The significant diversion of water away from the northern areas of Playgreen Lake likely has removed nutrients and food that were formerly available to the benthos. After 8MC became operational, the effects of the added inflow to the south portion of Kiskittogisu Lake were particularly noticeable. With the longest water renewal time of any of the areas examined, the enhanced amounts of particulate organic matter caused an increase in abundance of invertebrates in the south portion over the north portion of the lake. The invertebrates in the south portion probably also benefitted from increased primary productivity caused by enhanced nutrients in the inflow.

The decline in total numbers of benthos in Playgreen Lake between 1987 and 1989 was probably caused by drought conditions across the prairie region in 1988-1989. Reduced spring and summer flows through the south basin of Playgreen Lake and warmer than normal air temperatures in northern Manitoba produced higher than normal water temperatures in the lake. Taxa which prefer cool lake waters, such as Amphipoda, declined, while taxa, such as Oligochaetes, known to thrive in warm shallow habitats benefitted by the increased temperatures and/or reduced flow.

WATERFOWL

Concerns expressed by the Norway House Band that opportunities for hunting waterfowl in the fall had declined after the regulation of Lake Winnipeg resulted in a FEMP study of waterfowl in this area. The purpose of this study was to investigate current waterfowl use in the fall and, to the extent, possible, compare it with historical usage.

One-on-one interviews were conducted with 7 waterfowl hunters in Norway House on February 13, 1987. Hunters were asked to share their observations on changes in the numbers and distribution of waterfowl; this information was used in the determination of the locations and timing of the 1987 surveys. A series of low-altitude aerial surveys were flown in 1986 and 1987, along the shorelines of Playgreen, Kiskitto and Kiskittogisu lakes and 8-Mile Channel (Fig. 3.14). The 1986 surveys were flown on September 5 and 12 in a Cessna 185 with two observers; the 1987 surveys were flown on October 5 ,16, and 26 in a Bell 206B helicopter with one observer. Surveys were flown at altitudes of between 30 and 40 m above the ground or water surface.

A summary of the 1986 and 1987 survey data is shown in Fig 3.15. Maximum densities are recorded because they were more likely to represent the potential for waterfowl use. Densities were consistently higher in 1987 than in 1986; this may be a reflection of the different survey techniques used each year, or it may indicate that

Figure 3.14 Waterfowl Survey Routes in the Outlet Lakes Area, 1986 and 1987

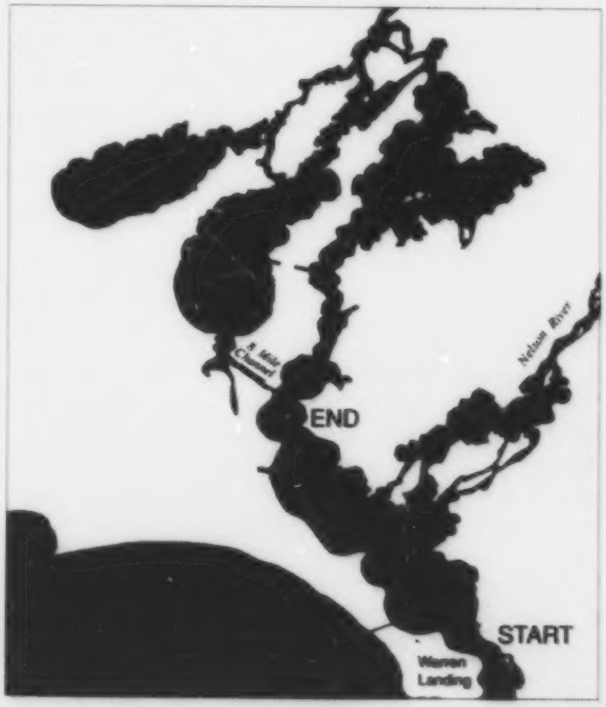


Figure 3.15 Waterfowl Densities[1] Observed during 1986/1987 Surveys of the Outlet Lakes Area

Diving Ducks	**Sep 5/86**	**Sep 12/86**	**Oct 5/87**	**Oct 16/87**	**Oct 26/87**
Playgreen-South Basin	0.00	0.07	0.67	1.46	2.37
Playgreen-North Basin	2.05	0.66	2.69	2.12	1.97
Kiskitto	0.12	0.00	0.00	0.13	N.S.
Kiskittogisu	0.25	0.33	1.04	0.00	0.00
Dabbling Ducks					
Playgreen-South Basin	0.03	0.00	1.19	3.06	0.24
Playgreen-North Basin	0.60	0.11	0.68	2.50	0.10
Kiskitto	0.00	0.00	0.30	0.00	N.S.
Kiskittogisu	0.30	0.00	1.36	4.58	0.00
Total Ducks[2]					
Playgreen-South Basin	0.03	0.07	2.26	4.86	2.37
Playgreen-North Basin	2.65	0.71	3.70	4.62	2.07
Kiskitto	0.12	0.00	0.30	0.13	N.S.
Kiskittogisu	0.55	0.33	2.40	4.58	0.00
Canada Geese					
Playgreen-South Basin	0.00	0.00	0.67	1.46	0.00
Playgreen-North Basin	0.10	0.19	0.11	0.16	0.00
Kiskitto	0.10	0.64	0.00	0.00	N.S.
Kiskittogisu	0.38	0.15	0.42	0.00	0.00

[1] Numbers shown are birds per kilometer based on survey lengths as follows: 396 km (Sept 5 and 12, 1986); 474 km (Oct 5, 1987); 333.3 km (Oct 16, 1987); and 292 km (Oct 26, 1987).

[2] Total ducks includes diving ducks, dabbling ducks, and unidentified ducks.

N.S.= not surveyed

X = highest density by area

the 1986 survey took place before large numbers of migrating waterfowl had reached the study area that year. There was considerable variation in waterfowl densities between surveys and sites, especially for dabblers (e.g. dabbler densities for the south basin of Playgreen Lake were 3.06 birds/km on October 16, 1987 and 0.24 birds/km for the same site on October 26, 1987).

The only historical data on the waterfowl use of the Outlet Lakes area are the results of two sets of aerial surveys conducted in 1972 and 1973 (LWCN 1975); these data are summarized in Fig. 3.16. As was the case with the 1986 and 1987 surveys, there was considerable variability in the waterfowl densities between surveys and sites in 1972 and 1973 (e.g. diver densities for the south basin of Playgreen Lake were 72.07 for September 7, 1973 and 14.21 for September 14, 1973).

Comparison of the 1972/1973 and 1986/1987 data suggest that diving ducks declined in the Outlet Lakes area by approximately 96%; declines were most apparent in the two basins of Playgreen Lake. It is risky, however,

Figure 3.16 Waterfowl Densities Observed during 1972/1973 Surveys of the Outlet Lakes Area

Diving Ducks	**Sep 24&25/72**	**Aug 30/73**	**Sept 7/73**	**Sept 14/73**	**Oct 6 /73**
Playgreen-South Basin	25.81	46.57	72.07	14.21	25.51
Playgreen-North Basin	63.15	102.01	N.S	8.19	N.S
Kiskitto	2.03	0.00	0.00	0.00	0.00
Kiskittogisu	4.83	1.88	0.00	0.00	3.24
Dabbling Ducks					
Playgreen-South Basin	1.49	0.00	0.11	0.00	0.85
Playgreen-North Basin	7.87	0.20	0.00	0.00	N.S
Kiskitto	0.90	0.00	0.00	0.77	0.00
Kiskittogisu	0.57	1.88	0.00	0.47	0.00
Total Ducks[2]					
Playgreen-South Basin	29.21	47.58	72.18	14.21	26.36
Playgreen-North Basin	71.02	104.22	N.S	8.51	N.S
Kiskitto	3.98	0.55	0.00	0.77	0.00
Kiskittogisu	8.39	3.22	0.00	0.47	3.24
Canada Geese					
Playgreen-South Basin	0.00	0.11	0.20	0.00	0.20
Playgreen-North Basin	0.78	0.44	N.S	0.14	N.S
Kiskitto	1.01	2.66	0.21	0.00	0.00
Kiskittogisu	1.13	0.27	0.22	0.51	0.45

[1] Numbers shown are birds per kilometer based on survey lengths as follows: 425.9 km (Sept 24 and 25, 1972); 220.2 km (Aug 30, 1973); 200.4 km (Sept. 7, 1973); 185.9 km (Sept 14, 1973); and 235.5 km (Oct 6, 1973)

[2] Total ducks includes diving ducks, dabbling ducks, and unidentified ducks.

N.S= not surveyed

X = highest density by area

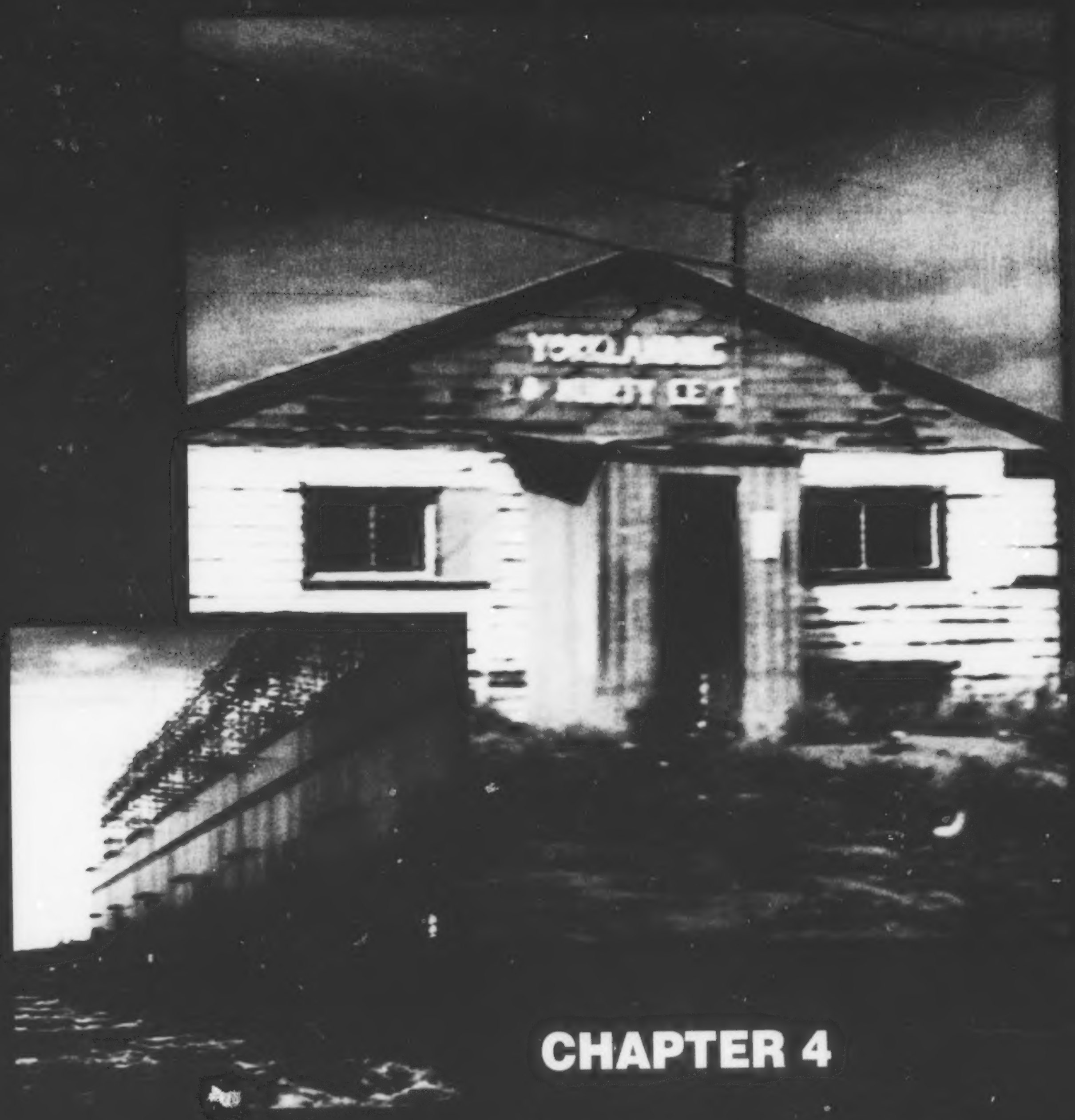
to draw broad conclusions about diver numbers on the basis of the 1972/1973 and 1986/1987 surveys, because both surveys provide only a limited number of "point-in-time" counts. Furthermore large between-year changes are not uncommon in waterfowl counts derived from aerial surveys. The data suggest that the Outlet Lakes area did not attract large numbers of dabbling ducks in either of the two survey periods. Similarly, only relatively small numbers of Canada geese were observed on individual surveys in both survey periods; indeed, no geese were observed on several surveys.

Two possible causes for the apparent change in diving ducks were considered: 1) changes in regional populations; and 2) modifications to the local physical environment and waterfowl habitat. The only data on regional populations are the annual breeding pair surveys conducted by the U.S. Fish and Wildlife Service (USF & WS) in northern Manitoba. These data provide adjusted population estimates for ducks and serve as general indicators of population size and trends. These data estimate the size of breeding populations; they do not indicate the size of fall migrating flocks.

Data from Stratum 24, the USF & WS region, which most closely approximate the FEMP study area, were reviewed for the periods 1964 - 1975 and 1977 - 1988. When the 12-year means for the two periods were compared, a small increase (approximately 2.6%) in diving ducks was found. However, large year-to-year fluctuations occurred during these periods; thus, the means on which these changes were based would vary somewhat as individual year counts were added or subtracted. The apparent reduction in diving duck use of the Outlet lakes area does not appear to be a reflection of a long-term decline in regional populations as represented by the Stratum 24 counts, since no such trends were evident in the stratum data.

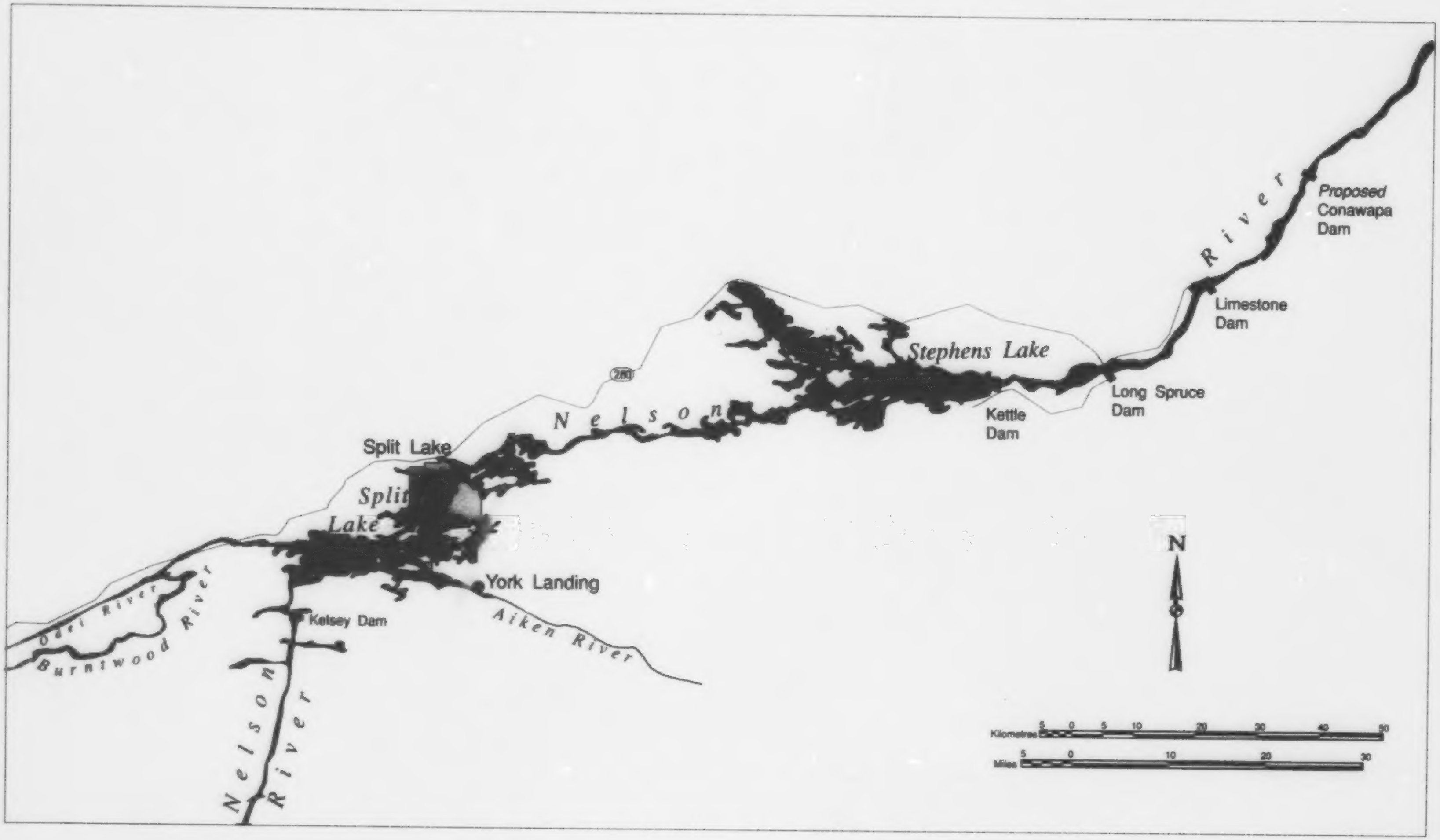
Modifications to the local physical environment and waterfowl habitat was the second possible cause considered for the apparent decrease in diving ducks. In particular, it was postulated that environmental changes might have caused a reduction in the availability of invertebrate food items in Playgreen Lake and/or a general reduction in the attractiveness of Playgreen Lake to diving ducks. No data are available on the abundance of benthic invertebrates in Playgreen Lake during the fall waterfowl staging period of September and October; consequently, no firm conclusions can be drawn regarding the abundance or availability of benthic invertebrates to fall staging diving ducks. Possible changes in environmental stimuli such as emergent vegetation, underwater visibility, and the appearance of the shoreline, may have reduced the potential of the habitat to attract diving ducks. Unfortunately, there is no direct experimental or survey proof to either validate or negate either of these postulated causes of the apparent decrease in diving ducks.

In summary, low numbers of ducks and Canada geese were observed in September 1986 and October 1987 in the Outlet Lakes area. Temporal and spatial data, as well as current data, were too limited to estimate changes in the waterfowl use of this area with any degree of confidence. The data suggest, however, that there may have been a decline in the diving duck use of this area following the regulation of Lake Winnipeg.



CHAPTER 4

SPLIT LAKE AREA


Proposed Conawapa Dam
River
Limestone Dam
Stephens Lake
Long Spruce Dam
Kettle Dam
280
Nelson
Split Lake
Split Lake
York Landing
N
Odei River
Burntwood River
Kelsey Dam
Aiken River
Nelson River
Kilometres 5 0 5 10 20 30 40 50
Miles 5 0 10 20 30

MORPHOLOGY AND SEDIMENT REGIMES

Introduction

The focus of the FEMP morphological study was the Churchill River Diversion (CRD) route, the region of the greatest morphological changes in the FEMP study area. In particular, a series of air photos was analyzed to determine the feasibility of air photo interpretation as a means of assessing past morphological changes along the CRD. Most of the results of this analysis were reported on in chapter 2; the results of the analysis for the First Rapids area are included in this chapter because of the proximity of this site to Split Lake.

Data on suspended sediment were collected at four sites in the Split Lake area as part of the FEMP water quality study; these data are summarized in this section. A brief discussion of suggested studies to better assess the changes in the morphology and sediment regime in the Split Lake area concludes this section.

First Rapids

First Rapids is located approximately 14 km upstream of the confluence of the Burntwood River with the Odei River, in an area composed of glaciolacustrine basin deposits consisting of clay and silt, 2 to 15 m thick. Prior to the diversion, bedrock was exposed on both channel banks at First Rapids and the river channel was continuously confined by the valley walls. Downstream of First Rapids, the channel became much wider and the riverbanks consisted of high slopes composed of unconsolidated, likely lacustrine, sediments.

Inspection of pre-project photography indicated no detectable changes in channel morphometry had occurred in the vicinity of First Rapids in the period between 1950 and 1970. Comparative analyses of air photos indicated that the area of active channel at First Rapids increased from 22 000 m^2 in 1970 to 52 000 m^2 in 1981, with a further increase of 1 000 m^2 between 1981 and 1986. The area of active channel immediately downstream of First Rapids increased from 170 000 m^2 in 1970 to 208 000 m^2 in 1981 and 219 000 m^2 in 1985. Total area of active channel in the vicinity of First Rapids was 192 000 m^2 in 1970, 260 000 m^2 in 1981, and 272 000 m^2 in 1986 (Fig 4.1).

Figure 4.1 Estimated Changes in Active Channel Area and Volume of River Erosion in the Vicinity of First Rapids

Surface area of river in	*Total (m^2)*	*Change in surface area river in*	*(m^2)*
1970	192,000	1970-1981	68,000
1981	260,000	1970-1986	80,000
1986	272,000	1981-1986	12,000

Estimated volume of eroded material (m^3)	low	high
1970-1981	98,000	441,000
1970-1986	111,000	499,500
1981-1986	13,000	58,500

Average annual sediment production (tonnes/year)	low	high
1977-1981	21,600	97,000
1981-1986	3,600	16,100

Assuming bank heights of 2 m and 9 m, for 'low' and 'high' estimates respectively, the amount of sediment eroded in the vicinity of First Rapids was estimated to be as low as 13 000 m^3 between 1981 and 1986 and as high as 499 500 m^3 between 1970 and 1986. Much of the shoreline erosion occurred during an ice jam in 1980. Average annual rate of sediment production was estimated to be between 2.2 to 9.7 x 10^4 tonnes per year from 1977 to 1981 and between 0.4 to 1.6 x 10^4 tonnes per year from 1981 to 1986.

Split Lake

Turbidity, total dissolved solids (TDS), non-filterable residue (NFR), and colour were sampled (Fig. 4.2) at 4 sites in the Split Lake area as part of the FEMP water quality study. Mean turbidity levels at all 4 sites, including the natural river site on the Aiken River exceeded the Canadian Water Quality Guidelines for turbidity in drinking water of 5 NTU. There were also occasions, at all 4 sites, when colour exceeded the Canadian Water Quality Guideline for colour in drinking water of 15 TCU.

Figure 4.2 Turbidity, Total Dissolved Solids, Non-Filterable Residue, and Colour for the Split Lake Area, 1986 - 1989

Variable	Type	Units	Mean	SD	Max.	Min.
Aiken River at the Inlet to Split Lake[1]						
Turbidity	field	NTU	7.[+]	3.	16.[+]	2.[+]
	lab	NTU	6.[+]	4.	18.[+]	1.
TDS		mg·L^{-1}	104.	51.	212.	27.
NFR	total	mg·L^{-1}	5.	4.	18.	<1.
	fixed	mg·L^{-1}	3.	2.	8.	<1.
Colour	true	relative	46.[+]	25.	120.[+]	8.
Burntwood River at the Inlet to Split Lake.						
Turbidity	field	NTU	34.[+]	11.	70[+,++]	17.[+]
	lab	NTU	35.[+]	10.	71.[+,++]	20.[+]
TDS		mg·L^{-1}	65.	3.	71.	58.
NFR	total	mg·L^{-1}	24.	16.	107.	10.
	fixed	mg·L^{-1}	21.	15.	100.	8.
Colour	true	relative	22.[+]	6.	40.[+]	10.
Nelson River below Grass River						
Turbidity	field	NTU	12.[+]	7.	45.[+]	4.
	lab	NTU	9.[+]	3.	18.[+]	5.
TDS		mg·L^{-1}	154.	21.	195.	119.
NFR	total	mg·L^{-1}	5.	2.	11.	2.
	fixed	mg·L^{-1}	4.	2.	9.	<1.
Colour	true	relative	9.	5.	20.[+]	<5.
Nelson River at the Outlet of Split Lake.						
Turbidity	field	NTU	22.[+]	12.	88.[+,++]	13.[+]
	lab	NTU	18.[+]	5.	35.[+]	11.[+]
TDS		mg·L^{-1}	118.	16.	154.	93.
NFR	total	mg·L^{-1}	10.	4.	21.	4.
	fixed	mg·L^{-1}	8.	3.	19.	3.
Colour	true	relative	14.	6.	30.[+]	5.

[1] Sample period was Jan 1987 to Oct 1989

Footnotes

[+] Exceeds limit for drinking water

[++] Exceeds limit for protection of aquatic life

Exceedences in the "Max." column indicates occasional exceedences.

Mean turbidity and NFR values at the Burntwood River inlet to Split Lake were the highest of the 4 FEMP sample sites in the Split Lake area. These higher values were likely the result of the documented bank erosion near First Rapids. Mean turbidity levels for the Burntwood River at the inlet to Split Lake were almost 4 times more turbid than the water flowing into Split Lake from the Nelson River, while turbidity levels at the outlet of Split Lake were intermediate between the two upstream values.

Lack of pre-development data for the Burntwood River inlet to Split Lake prevented the identification of changes in turbidity or NFR at this site. However, analysis of the data record for upstream sites at Threepoint Lake and Thompson, as well the documented bank erosion along the CRD, suggest that turbidity likely increased at the Burntwood River inlet site. There was a 67% decline in NFR at the Nelson River site at the inlet to Split Lake. As discussed in the water quality section, water quality changes observed at this site appear to be restricted to the reach between Split and Sipiwesk lakes.

Comparison of the FEMP data collected at the outlet of Split Lake with pre-development data showed no change in mean turbidity levels (1987 - 1989: 18 NTU; 1972 - 1973: 17 NTU) or mean NFR levels (1987- 1989: 8 mg·L^{-1}; 1972 -1973: 6 mg·L^{-1}). Although NFR in the Burntwood River is significantly higher than in the Nelson River, a large amount of sediment, most especially from the lower diversion area, appears to have deposited in Split Lake. No studies of sedimentation rates have been conducted in Split Lake; however, on the basis of turbidity measurements and analyses of satellite images, it appears that most of the sediment has been deposited near the Burntwood River inlet forming a subaqueous delta.

A belief among Split Lake residents that the water is more turbid now than in the past was not substantiated by the results of the FEMP study; however, there are two possible explanations for this apparent difference. The limited spatial coverage of Split Lake in the FEMP study may have been too insensitive to detect localized changes in areas of particular interest to community residents, such as in the community's beach area, or alternatively Kelsey Dam might have caused an increase in turbidity immediately following its installation in the early 1960s, followed by a subsequent decrease as the Kelsey Dam forebay area stabilized. Any decrease in turbidity in Split Lake from the Nelson River would have been compensated for by increases from the Burntwood River, resulting in no detectable change during the sampling period. The virtual absence of pre-development data for the Kelsey Dam, and the paucity of data for the immediate post-impoundment period, make it difficult to examine this possibility. Unless some other data can be found and validated, it may not be possible to completely document the effects the LWCN project on the sediment regime of Split Lake.

Future Studies

For the lower CRD area, from First Rapids to Split Lake, the same basic morphological monitoring program is recommended as that for the upper CRD area, in the Threepoint and Footprint lakes area, namely: 1) to undertake field reconnaissance to ground truth the air photo interpretation; 2) to prepare planimetric mapping and classify shoreline characteristics; and 3) to obtain local participation in developing a classification system as relevant to the northern residents as possible. In addition, the re-survey of some river cross sections and the establishment of at least 2 sounding lines in Split Lake, immediately off the mouth of the Burntwood River, are recommended. In particular, the rate and spatial extent of sediment deposition in Split Lake, off the mouth of the Burntwood River should be determined, by using such methods as bathymetric surveys, sediment coring, and sedimentation pans.

WATER QUALITY

Introduction

A three-year water quality study, from January 1987 to October 1989, of 61 physical and chemical water quality variables was conducted at 11 sites in the FEMP study area; 4 of these 11 sites were located in the Split Lake area. This section presents the results of the water quality study for this area, as follows: 1) listings of those water quality variables whose values, from 1987 to 1989, exceeded the Canadian Water Quality Guidelines; 2) comparisons of current water quality conditions to historical conditions, to the extent that the data exists; 3) relationships, if any, between the water quality variables and river discharges; 4) differences in water quality conditions between the ice-free and ice-cover seasons; and 5) results of the limited bacteriological assessment of the recreational waters in and around the NFC communities.

Canadian Water Quality Guidelines, established in 1987, were used as a means for assessing the water quality in the FEMP study area. Major uses of water for which Guidelines have been developed include drinking water, recreational use and the protection of aquatic life. Variations in environmental conditions across Canada will affect water quality in different ways; hence, many of the Guidelines may need to be modified according to these local conditions. The use of the Guidelines for assessing adverse effects in the FEMP study area is limited in that they have not been established for all variables, they are not based on site-specific cause and effect studies in northern Manitoba, and they do not take into account the effect of cumulative stresses caused when the values of two or more water quality variables simultaneously exceed the guideline values. They are thus a suggestive, rather than a definitive, basis for assessing adverse effects in the FEMP study area.

Natural Sites

One of the 3 natural sites monitored in the FEMP water quality study was in the Split Lake area, on the Aiken River where it enters Split Lake (Fig. 4.3). These 3 sites were monitored to provide a measure of current water quality in natural rivers in the study area and, where sufficient historical data existed, to determine the degree of natural variation in water quality between the pre- and post-development study periods.

As was the case for the other 2 natural rivers, the water quality of the Aiken River was characterized by a number of variables which exceeded the Canadian Water Quality Guidelines. Mean values for turbidity, colour, extractable aluminum (AL), total copper (Cu) and extractable iron (Fe) all exceeded the Guidelines and there were sporadic occurrences when extractable manganese (Mn) exceeded the Guidelines (Figs. 4.2 + 4.4).

Due to the lack of pre-development water quality data and of any discharge data for the Aiken River, no analyses of temporal trends or of water quality - discharge relationships were possible for this site.

Distinct differences between the ice-free and ice-cover seasons were evident in 9 variables (Fig. 4.5). Alkalinity (total and bicarbonate), hardness, dissolved calcium (Ca), total ammonia (NH_3), dissolved inorganic carbon (DIC), and dissolved arsenic (As) and zinc (Zn) were higher under ice-cover, while chlorophyll a was lower. This is generally the same pattern as in the Footprint River natural site, suggesting a common cause.

Figure 4.3 FEMP Water Quality Sites in the Split Lake Area

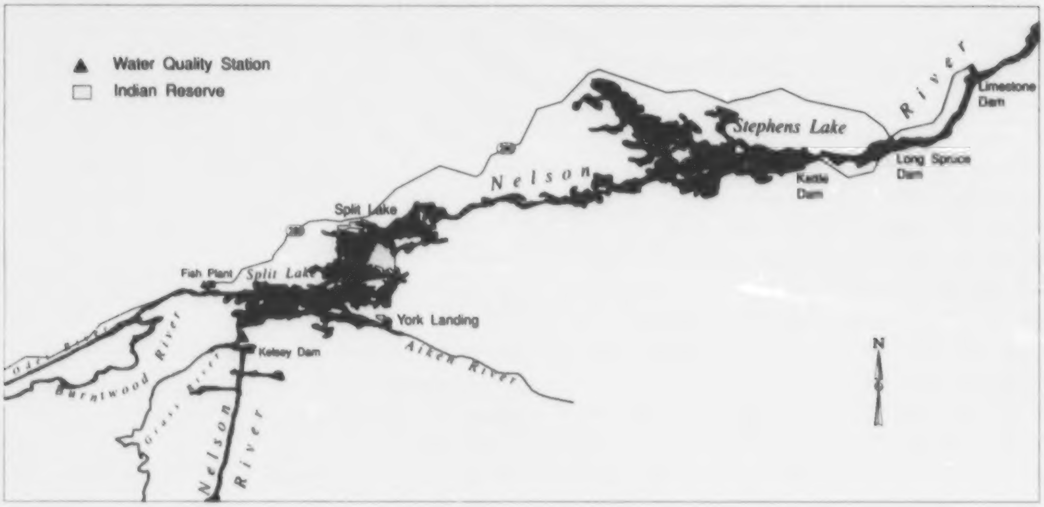

▲ Water Quality Station
☐ Indian Reserve
Stephens Lake
River
Limestone Dam
Long Spruce Dam
Kettle Dam
Nelson
Split Lake
Fish Plant
Split Lake
York Landing
Kelsey Dam
Aiken River
Burntwood River
Grass River
Nelson River
N

Figure 4.4 Water Quality Variables Which Exceeded the Canadian Guidelines for the Split Lake Area, 1986 - 1989

Variable	Type	Units	Mean	SD	Max.	Min.
Aiken River at the Inlet to Split Lake, Jan 1987 - Oct 1989						
Al	extractable	$mg \cdot L^{-1}$	0.107^{++}	0.059	0.226^{++}	<0.100
Cu	total	$mg \cdot L^{-1}$	0.0029^{++}	0.0041	0.0170^{++}	<0.0005
Fe	extractable	$mg \cdot L^{-1}$	$0.438^{+,++}$	1.008	$5.980^{+,++}$	0.101
Mn	extractable	$mg \cdot L^{-1}$	0.093^{+}	0.339	1.920^{+}	0.005
Burntwood River at the Inlet to Split Lake, Sept 1986 - Oct 1989						
Al	extractable	$mg \cdot L^{-1}$	0.592^{++}	0.315	2.140^{++}	0.235^{++}
Cd	total	$mg \cdot L^{-1}$	<0.0001	0.0001	0.0003^{++}	<0.0001
Cu	total	$mg \cdot L^{-1}$	0.0048^{++}	0.0062	0.0278^{++}	0.0010
Fe	extractable	$mg \cdot L^{-1}$	$0.774^{+,++}$	0.416	$2.860^{+,++}$	0.299
Pb	total	$mg \cdot L^{-1}$	0.0010	0.0007	0.0034^{++}	<0.0007
Mn	extractable	$mg \cdot L^{-1}$	0.030	0.027	0.177^{+}	0.004
Nelson River below Grass River, Sept 1986 - Oct 1989						
Al	extractable	$mg \cdot L^{-1}$	0.188^{++}	0.101	0.418^{++}	<0.100
Cu	total	$mg \cdot L^{-1}$	0.0037^{++}	0.0043	0.0159^{++}	0.0010
Fe	extractable	$mg \cdot L^{-1}$	0.196	0.074	0.409^{++}	0.045
Nelson River at the Outlet of Split Lake, Sept 1986 - Oct 1989						
Al	extractable	$mg \cdot L^{-1}$	0.315^{++}	0.126	0.651^{++}	<0.100
Cu	total	$mg \cdot L^{-1}$	0.0050^{++}	0.0075	0.0308^{++}	0.0010
Fe	extractable	$mg \cdot L^{-1}$	$0.389^{+,++}$	0.110	$0.672^{+,++}$	0.129
Pb	total	$mg \cdot L^{-1}$	0.0009	0.0011	0.0066^{++}	<0.0007

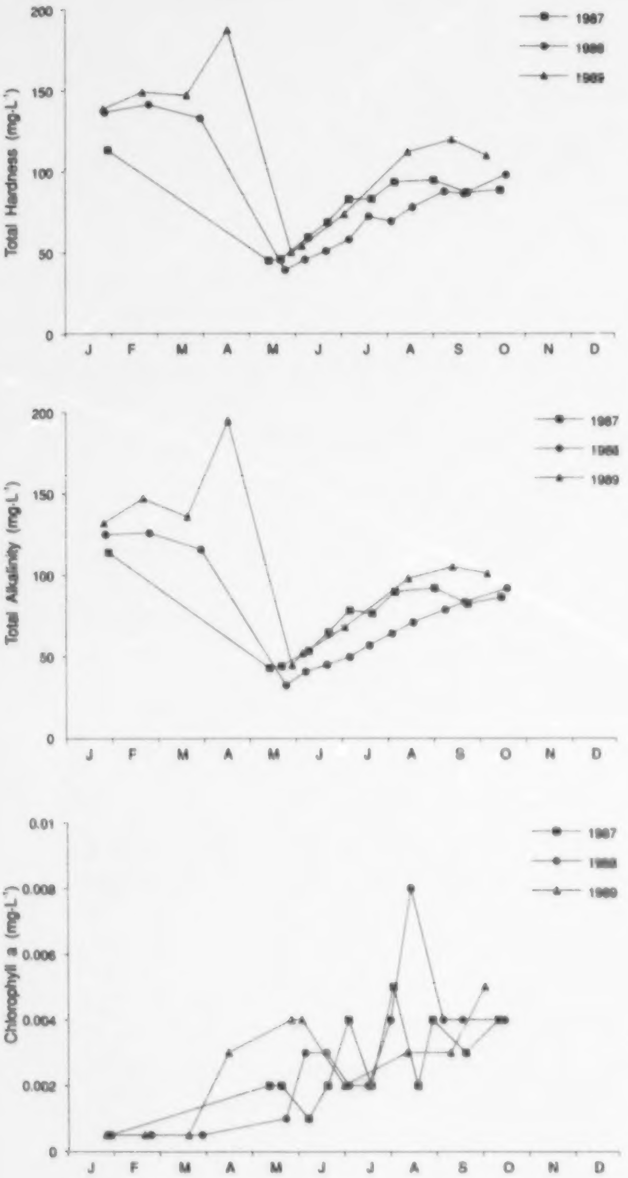
Footnotes

$^{+}$ Exceeds limit for drinking water

$^{++}$ Exceeds limit for protection of aquatic life

Exceedences in the "Max." column indicates occasional exceedences.

Figure 4.5 Seasonal Water Quality Trends for Selected Water Quality Variables in the Aiken River



Split Lake Inlets

Two FEMP sample sites were located on the two major inlets to Split Lake: the Burntwood River and the Nelson River (Fig. 4.3). Water quality at the Burntwood River inlet to Split Lake, during 1987 - 1989, was typical for the Burntwood River below the confluence with the Churchill River diversion. Concentrations of all but two variables were the same as at the Thompson site; the exceptions were the 45 - 50% higher concentrations for the annual mean total and fixed non-filterable residue (NFR). Mean levels for turbidity, colour, extractable Al, total Cu, and extractable Fe all exceeded the Canadian Water Quality guidelines; there were sporadic occasions when total cadmium (Cd), lead (Pb) and extractable manganese (Mn) exceeded the guidelines (Figs. 4.2 + 4.4).

Physical and chemical water quality in the Nelson River at the inlet to Split Lake, during 1987 - 1989, was not significantly different in any aspect from that at Sea River Falls, upstream. Mean levels of turbidity, extractable Al and total Cu all exceeded the Canadian Water Quality Guidelines; there were sporadic occasions when colour and extractable Fe exceeded the guidelines (Figs. 4.2 + 4.4).

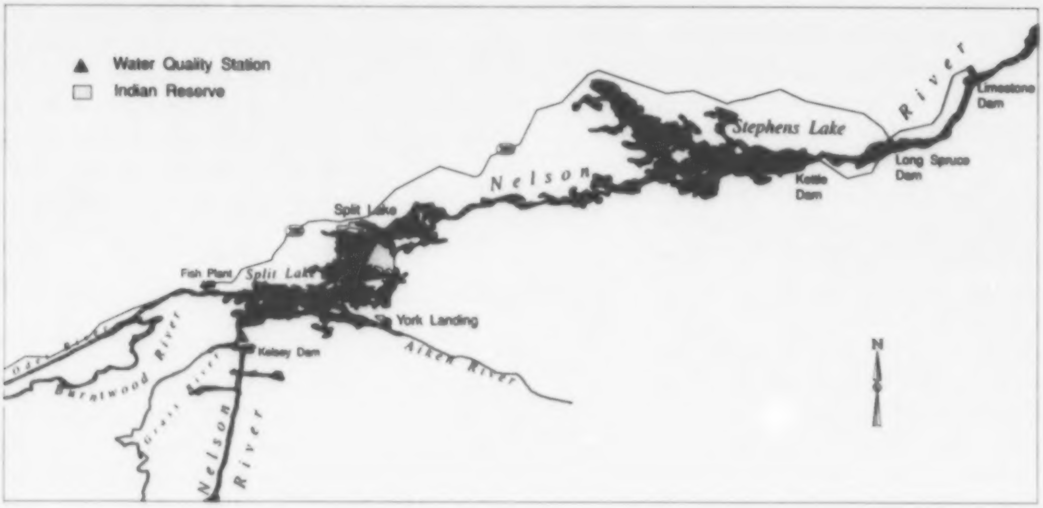
No quantitative analysis of changes in water quality since the Churchill River diversion is possible for the Burntwood River inlet site due to lack of pre-development data; however, it is likely that changes in water quality at this site were similar to those documented upstream at Thompson. Several significant differences were noted for the Nelson River inlet site between the 1971 - 1974 pre-development period and the 1987 - 1989 FEMP period (Fig. 4.6) (e.g. declines in NFR, total dissolved phosphate (TDP) and total dissolved nitrogen (TDN) of 67, 45 and 22% respectively). These changes appear to have been restricted to the reach between Sipiwesk and Split lakes. Some of these changes might be explained by a natural evolution of limnological conditions in the Kelsey Generating Station forebay or alternatively they may be due to the temporary decrease in erosion rates as a result of the lower Nelson River flows. Between 1987 and 1989 Nelson River flows were at or near the lowest observed in the past 30 years. Additional sampling, in periods of non-drought conditions, is required to properly determine if the LWCN project has had any long-term impact on water quality at this site.

Figure 4.6 Changes in Selected Water Quality Variables in the Nelson River near the Inlet of Split Lake from 1972/1973 to 1987/1989

	NFR NTU	**Diss Ca** mg·L⁻¹	**TDP** mg·L⁻¹	**TDN** mg·L⁻¹	**Diss Fe** mg·L⁻¹
X_{pre}	15.0	28.5	0.020	0.388	0.113
X_{post}	5.0	29.3	0.011	0.304	0.039

X_{pre}=1972/1973 mean; x_{post} = 1987/1989 mean

Figure 4.3 FEMP Water Quality Sites in the Split Lake Area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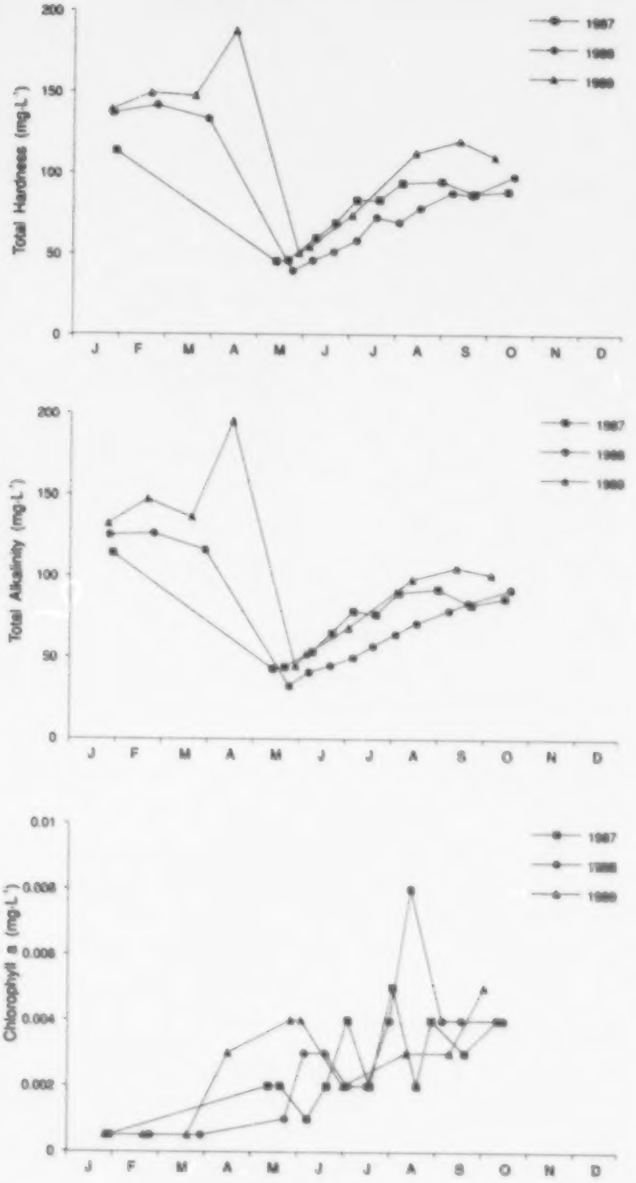

Figure 4.5 Seasonal Water Quality Trends for Selected Water Quality Variables in the Aiken River

Split Lake Inlets

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Physical and chemical water quality in the Nelson River at the inlet to Split Lake, during 1987 - 1989, was not significantly different in any aspect from that at Sea River Falls, upstream. Mean levels of turbidity, extractable Al and total Cu all exceeded the Canadian Water Quality Guidelines; there were sporadic occasions when colour and extractable Fe exceeded the guidelines (Figs. 4.2 + 4.4).

No quantitative analysis of changes in water quality since the Churchill River diversion is possible for the Burntwood River inlet site due to lack of pre-development data; however, it is likely that changes in water quality at this site were similar to those documented upstream at Thompson. Several significant differences were noted for the Nelson River inlet site between the 1971 - 1974 pre-development period and the 1987 - 1989 FEMP period (Fig. 4.6) (e.g. declines in NFR, total dissolved phosphate (TDP) and total dissolved nitrogen (TDN) of 67, 45 and 22% respectively). These changes appear to have been restricted to the reach between Sipiwesk and Split lakes. Some of these changes might be explained by a natural evolution of limnological conditions in the Kelsey Generating Station forebay or alternatively they may be due to the temporary decrease in erosion rates as a result of the lower Nelson River flows. Between 1987 and 1989 Nelson River flows were at or near the lowest observed in the past 30 years. Additional sampling, in periods of non-drought conditions, is required to properly determine if the LWCN project has had any long-term impact on water quality at this site.

Figure 4.6 Changes in Selected Water Quality Variables in the Nelson River near the Inlet of Split Lake from 1972/1973 to 1987/1989

	NFR	**Diss Ca**	**TDP**	**TDN**	**Diss Fe**
	NTU	mg·L⁻¹	mg·L⁻¹	mg·L⁻¹	mg·L⁻¹
X_{pre}	15.0	28.5	0.020	0.388	0.113
X_{post}	5.0	29.3	0.011	0.304	0.039

X_{pre}=1972/1973 mean; x_{post} = 1987/1989 mean

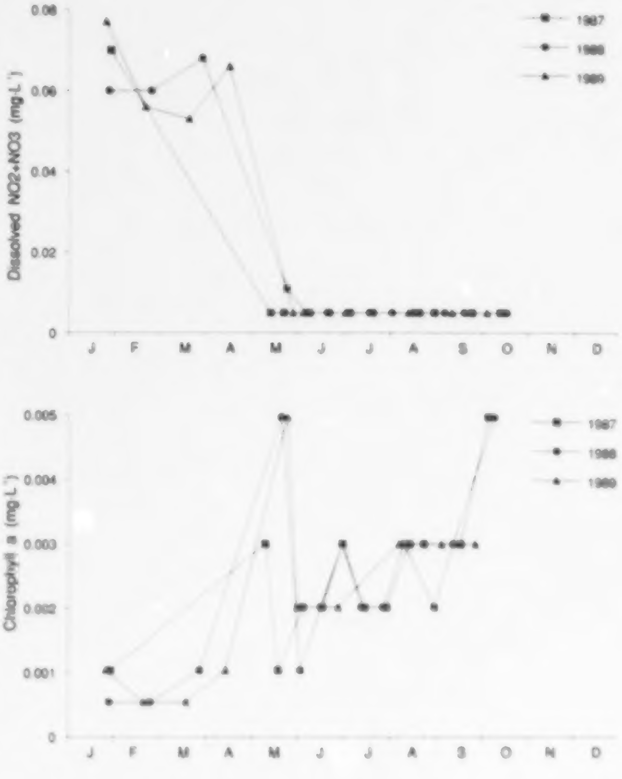
Positive correlations with discharge dominated at the Burntwood River inlet site during 1987 - 1989, consistent with the FEMP findings at sites upstream on the Burntwood River. The positive correlates, which included turbidity, are evidence of the increased importance of eroded shoreline materials in regulating water quality. However, none of the relationships was strong enough to show much impact prediction or management potential.

Fewer variables were significantly correlated with discharge at the Nelson River inlet site than at sites in the Burntwood River drainage or upstream on the Nelson River. Most of the significant correlations had positive slopes, but none of the significant correlations were particularly strong. None of the significant correlations with discharge for the 1987 - 1989 period resembled any which existed during the pre-development (1972 - 1973) period. The pre-development discharge relationships at this site followed the trends evident in the natural rivers and in the Burntwood River at Thompson prior to development, with negative correlates dominating and positive correlations restricted to variables associated with particulate matter or suspended sediments. The cause of these changes is less clear than was the case at sites on the Burntwood River. Additional sampling during periods of higher discharge is required to determine if the relationships observed during the FEMP study are representative of current conditions or if some other relationships represent the usual post-development condition.

Concentrations of dissolved NO_2-NO_3 at the Burntwood River inlet site were higher under ice-cover, while chlorophyll a levels were lower under ice-cover than in the open-water season (Fig. 4.7). The causes of these seasonal patterns, which were also observed at sites upstream on the Burntwood River, were probably the same as at the upstream sites, which were discussed in chapter 2.

Few variables at the Nelson River inlet site showed marked differences between the open-water and ice-cover seasons during 1987 - 1989, although conductivity, hardness, dissolved magnesium (Mg) and dissolved NO_2-NO_3 tended to be higher under ice cover (Fig. 4.8). The pre-development database for this site is insufficient to conduct a quantitative analysis of the differences between the ice-free and ice-cover seasons; however, a qualitative analysis suggests that the seasonal patterns of several variables were somewhat different during the pre-development period than during the FEMP study. As noted previously, low Nelson River flows during the FEMP study may have been responsible for the observed values.

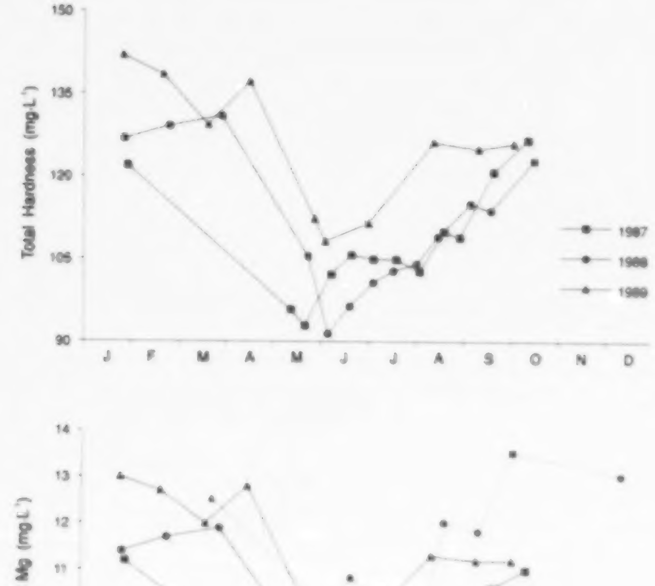
Figure 4.7 ***Seasonal Water Quality Trends for Selected Water Quality Variables in the Burntwood River at the Inlet to Split Lake***



Split Lake Outlet

Water quality at the outlet of Split Lake, from 1987 to 1989, shared a number of general similarities with sites upstream on the Nelson River. Mean levels of turbidity, extractable Al and total Cu exceeded the guidelines at all the Nelson River sites (Figs. 4.2 + 4.4); however water quality at the outlet of Split Lake differed from the other upper Nelson River sites in the magnitude by which these guidelines were exceeded. For example, turbidity and extractable Al at the outlet of Split Lake exceeded the guidelines by factors of 4 and 3.2 respectively, but only by factors of 2 on average at the other upper Nelson River sites. Another difference between the Split Lake outlet and other upper Nelson River sites was the greater

Figure 4.8 Seasonal Water Quality Trends for Selected Water Quality Variables in the Nelson River at the Inlet to Split Lake



concentration of extractable Fe at the Split Lake outlet; the higher levels appear to be a direct result of the Churchill River diversion. Other characteristics of the water quality at the Split Lake outlet include the sporadic occurrences of total lead (Pb) and colour at levels above the guidelines.

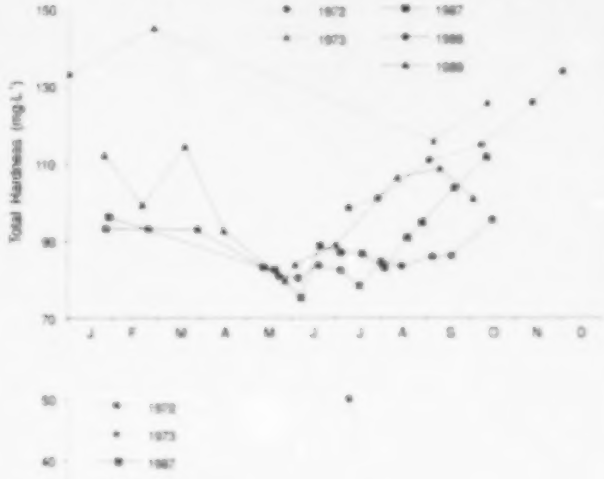
Statistical analysis of pre-development data (1972 - 1973) and post-development data revealed significant declines had occurred in a number of variables (e.g. conductivity, hardness, major ions, etc., (Fig. 4.6); most of the changes were solely attributable to the increased flows of softer water from the Churchill River drainage basin into Split Lake as a result of the diversion. An increase in extractable Fe, and significant decreases in total dissolved solids (TDS), dissolved inorganic carbon (DIC) and dissolved arsenic (As) were inferred on the bases of current differences in concentration between the Burntwood and Nelson rivers and the relative contribution of these rivers to total inflow.

Analysis of the FEMP data does not indicate that the Churchill River diversion has caused a significant increase in annual mean water turbidity (1972 - 1973 mean, 17 NTU; 1987 - 1989 mean, 18 NTU) or suspended sediment concentration (NFR fixed: 1972 - 1973 mean, 6 mg·L^{-1}; 1987 - 1989 mean, 8 mg·L^{-1}) or a decrease in water transparency, despite the much higher suspended sediment concentrations in the Burntwood River than in the Nelson River. Much of the suspended sediment load of the Burntwood River appears to settle out near the mouth, preventing a general increase in suspended sediment levels in the lake or downstream.

Only 3 variables were significantly correlated with discharge in the 1987 - 1989 study period; all correlations were positive and were not particularly strong. There were 10 water quality - discharge relationships for the pre-development period, based on data for two sites near the outlet of Split Lake; all correlations were negative and fairly strong. The shift from negative to positive correlations at the Split Lake outlet, although consistent with the changes in the discharge relationships in the Burntwood River following diversion, cannot be conclusively attributed to the diversion. Similar changes in the discharge relationships in the Nelson River at the inlet to Split Lake suggest a possible influence of the low Nelson River flows during the FEMP study or possibly some impact of the LWCN project on the upper Nelson River and Lake Winnipeg. Additional sampling during a period of higher Nelson River flows is required to determine the cause of the change in the discharge relationships at the outlet of Split Lake.

In contrast to the pre-development period, few variables occurred in different concentrations under ice-cover than in the open-water season during the FEMP study and none was common to the pre- and post-development periods (Fig. 4.9). Those which showed some evidence of seasonal variation after development (e.g. dissolved NO_2-NO_3) occurred in higher concentrations under ice-cover; this occurrence is generally consistent with the higher levels in both major inflows during the ice-cover period. The absence of seasonal differences in several variables during the FEMP study could be due to one or more of the several changes in the water regime which have occurred. For example the low Nelson River flows during the FEMP study period may have disrupted the normal discharge relationships and accompanying seasonal trends. Alternatively, the reversal of the natural seasonal flow regime, due to the operation of Jenpeg, has diminished the difference between the highest and lowest monthly mean flows at the outlet of Split Lake; this may have been sufficient to eliminate the rather small seasonal differences that prevailed prior to development.

Figure 4.9 Seasonal Water Quality Trends for Selected Water Quality Variables in the Nelson River at the Outlet of Split Lake



Bacteriological Assessment

A bacteriological assessment of the recreational waters in the Split Lake and York Landing areas was conducted in 1987. Seasonal studies were conducted from May to September at 5 sites at Split Lake and 4 sites at York Landing; in addition, an intensive study in the vicinity of the sewage treatment plant at Split Lake was conducted in August. The geometric mean fecal coliform bacteria for the seasonal studies ranged between 6 and 37 per 100 mL at Split Lake and 1 and 10 per 100 mL at York Landing. The geometric mean for the intensive study was 21 per 100 mL. Comparison of the results of the intensive study to the Health and Welfare Canada Recreational Water Quality Guideline of 200 bacteria per 100 mL indicates that the bacteriological water quality at this site was generally acceptable for recreational water uses. Limited sampling frequency for the seasonal studies precludes direct comparison of their results to this guideline.

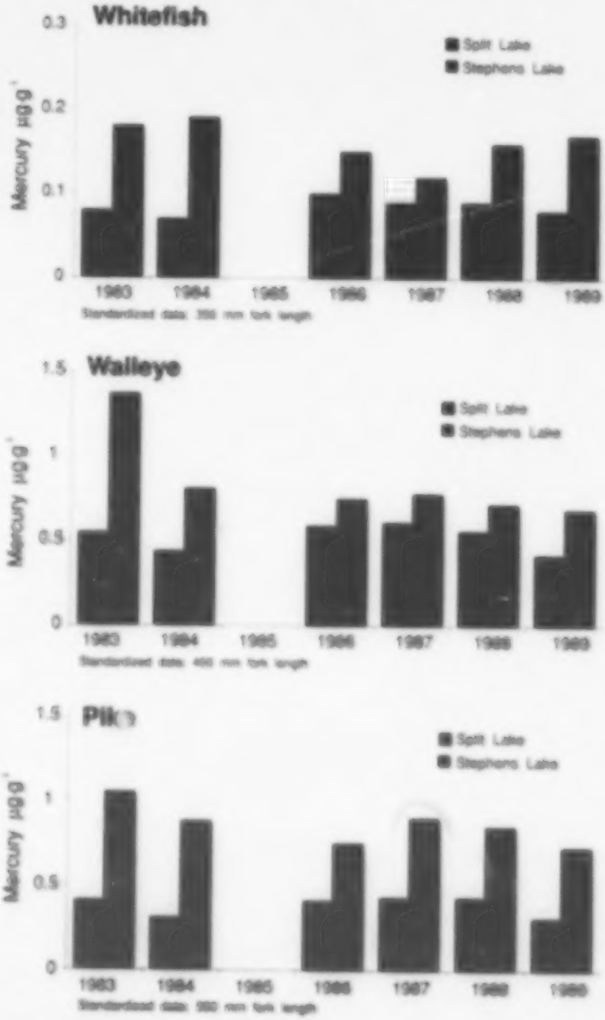
MERCURY

The FEMP mercury program focused on the Churchill River Diversion (CRD) route since this was the region within the FEMP study area that has experienced the most severe mercury problem. The basic processes that govern the production of methyl mercury, the expected longevity of elevated mercury levels in fish, and possible mitigative measures were discussed in chapter 2. Only mercury issues specific to the Split Lake area are discussed in this chapter, namely: 1) current mercury levels in fish in Split and Stephens lakes; 2) current mercury levels in residents of Split Lake and York Landing; and 3) a discussion of the possible factors affecting mercury levels in fish in Split Lake.

Mercury levels in fish in Split and Stephens lakes were sampled by the Manitoba Department of Natural Resources (Fig. 4.10). Whitefish mercury levels in Split Lake were within the average for northern Manitoba lakes remote from hydro development (less than 0.1 $\mu g\,g^{-1}$). Mercury levels in walleye from Split Lake ranged from 0.42 to 0.61 $\mu g\,g^{-1}$ during the period 1983-1989, while mercury levels in pike from Split Lake were slightly lower, ranging from 0.31 to 0.41 $\mu g\,g^{-1}$ during this period.

Whitefish mercury levels in Stephens Lake were approximately double those of Split Lake. Walleye mercury levels in Stephens Lake declined significantly from 1.37 $\mu g\,g^{-1}$ in 1983 to 0.8 $\mu g\,g^{-1}$ in 1984 and stabilized near this lower level from 1984 to 1989. As late as 1989, 18 years after impoundment, mercury levels in walleye were 3 times higher than the pre-development level of 0.25 $\mu g\,g^{-1}$ reported for Moose Lake, which was inundated in the formation of Stephens Lake. Pike mercury levels in Stephens Lake also declined significantly from 1.05 to 0.75 $\mu g\,g^{-1}$ between 1983 and 1986 and remained near this lower level through 1989. In 1989, mercury levels were 4 times the pre-development concentration of 0.20 $\mu g\,g^{-1}$ reported for Moose Lake.

Figure 4.10 Standardized Mean Muscle Mercury Concentrations for Fish in Split and Stephens Lakes, 1983 - 1989



Mercury levels in residents of Split Lake and York Landing were monitored by Health and Welfare Canada (Fig. 4.11). Of the approximately 15% of the population of Split Lake tested in 1989/90, 98% had values in the range of 0-19 ppb, which is considered to be in the "normal" range: the remaining values were in the range of 20-50 ppb. All of the women of childbearing age who were tested had values in the 0-19 ppb range.

Of the approximately 33% of the population of York Landing tested in 1988/89, 98% had values in the range of 0-19 ppb, with the remaining values being in the range of 20-50 ppb. All of the women of childbearing age who were sampled had values in the 0-19 ppb range. Unlike South Indian Lake and Nelson House, there were never any mercury levels in the tested populations of Split Lake and York Landing that exceeded 99 ppb.

Because the mercury levels in walleye and pike in Split Lake exceed 0.2 $\mu g\,g^{-1}$, residents of Split Lake and York Landing, with mercury levels in excess of 20 ppb, have been advised by Health and Welfare Canada to avoid the consumption of these species as a staple in their diet. This restriction has caused concern in the communities and raised questions regarding the effect of past hydro development on fish mercury levels in the lake.

While mercury levels in pike and walleye from Split Lake are not unusual in comparison to the natural range in northern Manitoba, they do appear to be uncharacteristically high for non-flooded lakes in the FEMP study area. The seemingly high mercury levels in walleye and pike are not related to the diversion of the Churchill River as they were prevalent before the diversion began operating (Fig. 4.12). Furthermore, as noted in chapter 2, measurements of methyl mercury in water in 1989 indicated methyl mercury produced in Notigi Reservoir does not travel as far as Thompson, and therefore could not be affecting fish mercury levels in Split Lake, farther downstream.

Figure 4.11 Mercury Levels in Residents of Split Lake and York Landing

Mercury Levels in Residents of Split Lake

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1976	31	25	6	0
1977	22	20	2	0
1978	0	0	0	0
1979	170	145	25	0
1980	54	33	21	0
1981	240	204	36	0
1982	167	142	25	0
1983	9	9	0	0
1984	111	94	17	0
1985	66	53	13	0
1989-90	192	189	3	0

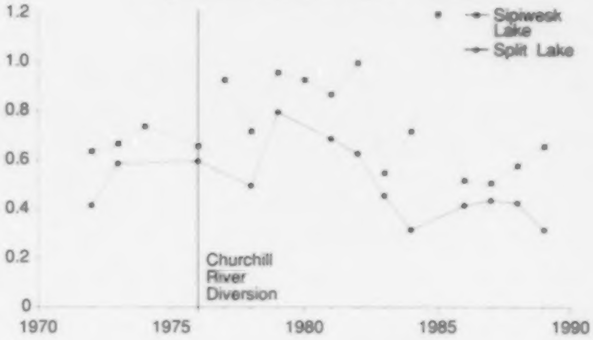
1989-90 Groups	*Sample Number*	*0 - 19 ppb*	*20 - 50 ppb*	*50 - 80 ppb*
Men	31	28	3	0
Women:				
12-45 yrs	26	26	0	0
over 45 yrs	9	9	0	0
Children:				
1-4 yrs	9	9	0	0
5-12 yrs	117	117	0	0

Mercury Levels in Residents of York Landing

Year	*Sample Number*	*0 - 19 ppb*	*20 - 99 ppb*	*>99 ppb*
1976	17	9	8	0
1977	21	15	6	0
1978	0	0	0	0
1979	73	56	17	0
1980	0	0	0	0
1981	169	159	10	0
1982	6	3	3	0
1983	5	5	0	0
1984	41	26	15	0
1985	37	31	6	0
1989-90	102	100	2	0

1989-90 Groups	*Sample Number*	*0 - 19 ppb*	*20 - 50 ppb*	*50 - 80 ppb*
Men	23	21	2	0
Women:				
12-45 yrs	29	29	0	0
over 45 yrs	11	11	0	0
Children:				
1-4 yrs	14	14	0	0
5-12 yrs	25	25	0	0

Figure 4.12 Mean Total Mercury Concentrations in Northern Pike from Split and Sipiwesk Lakes, 1972 - 1989



The most likely explanation is that there is a methyl mercury source situated upstream in the Nelson River. Sipiwesk Lake, the Kelsey Dam forebay, and fish killed in the Kelsey Dam turbines are potential sources. The potential for methyl mercury export to Split Lake could be examined through a series of measurements of methyl mercury in water along the Nelson River and in the other major inflows to the lake. These data would indicate the locations of any site of elevated methyl mercury production and determine if the methyl mercury is entering Split Lake. The importance of fish movements from Sipiwesk Lake and the Kelsey forebay could be documented using a tagging program, as has been employed at Missi Falls, at the outlet of Southern Indian Lake. If neither of these studies find a methyl mercury source which can explain the fish mercury levels in Split Lake, then the potential effect of fish killed in the Kelsey turbines or of a site of elevated net methylation within Split Lake should be investigated.

CHAPTER 5

FEMP CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This chapter presents the major FEMP conclusions and recommendations. The material in this chapter is organized into seven main topics: Water Quantity and Quality; Sediment and Morphology; Mercury; Fisheries and Aquatic Life; Waterfowl; Resource Harvesting; and Future Studies. The foundation for the conclusions and recommendations presented in this chapter was laid in the previous nine chapters of this two-volume Final Report.

CONCLUSIONS

Water Quantity and Quality

The hydrologic regime of the lakes and rivers in the FEMP study area under regulated conditions, for the period 1979 to 1988, was dramatically different from that for estimated natural flow conditions, for the same period. The type and magnitude of the changes in the hydrologic regime within the FEMP study area varied according to location relative to the hydroelectric control structures and dams, and included changes in annual mean flows, seasonal distribution of flows, range of daily fluctuations, and lake surface areas.

Regulation of the lakes and rivers of the FEMP study area by the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project has been extensive: 1) most of the Churchill River has been diverted at Southern Indian Lake into the Rat and Burntwood rivers and from these rivers into the lower Nelson River; 2) Lake Winnipeg has been regulated by a series of control structures in the Outlet Lakes area at the north end of Lake Winnipeg; and 3) five dams have been built along the Nelson River - Jenpeg, Kettle, Kelsey, Long Spruce, and Limestone, with approval currently being sought to proceed with a sixth dam, Conawapa. Construction of the LWCN project began in the early 1970s and is expected to continue well into the next century.

The flows of natural rivers, those unregulated by man-made structures, are affected by many factors such as the river basin's climate, (especially precipitation patterns and evaporation rates), topography, soil permeability, and vegetation; consequently, the river's flow can vary over the course of the year and from year to year. Thus, it is necessary, in assessing the impact of regulation, to estimate natural flows for the period of interest for comparison to regulated flows; average pre-regulation flows may not accurately represent what the natural flows would have been in the post-regulation period, without regulation.

Annual mean flows at Missi Falls decreased from an estimated natural range for the period 1979 to 1988 of 600 to 1700 $m^{3} \cdot s^{-1}$ to a range, usually, of 13 to 200 $m^{3} \cdot s^{-1}$ under regulation (except for brief excursions to flows as high as 1400 $m^{3} \cdot s^{-1}$). Flows at Thompson, on the Burntwood River, increased from an estimated natural annual mean of 93 $m^{3} \cdot s^{-1}$ to 888 $m^{3} \cdot s^{-1}$ under regulation. Flows along the lower Nelson River, downstream of its confluence with the Burntwood River at Split Lake, increased significantly following regulation. For example, the annual mean flows at Kettle Dam increased from an estimated value of 2170 $m^{3} \cdot s^{-1}$ under natural conditions, for the period 1979 to 1988, to 2980 $m^{3} \cdot s^{-1}$ under regulation. The long-term mean for this location is 2276 $m^{3} \cdot s^{-1}$; the 1980s was a dry decade in comparison to the long-term record for the FEMP study area.

Changes in the seasonal distribution of flows were most apparent on the Nelson River as it enters Cross Lake. While the estimated natural annual mean flow for 1979 to 1988 was not significantly different here from that under regulation (1829 $m^{3} \cdot s^{-1}$), the mean June to August discharge for the period 1979 to 1988 was 670 to 770 $m^{3} \cdot s^{-1}$ lower than estimated natural flows and the mean December to February discharge for this same period was 520 to 750 $m^{3} \cdot s^{-1}$ higher than estimated natural flows. The reversal of the seasonal pattern is obscured on the lower Nelson River by the addition of the diverted Churchill River flows which have caused even regulated low summer flows to be as high or higher than what they would have been otherwise. For example, at Kettle, the mean June to August discharge for 1979 to 1988 was approximately 190 $m^{3} \cdot s^{-1}$ more than the estimated natural flow for this period, without regulation and diversion. Overall, the alteration in seasonal distribution of flows has shifted 7% of the combined annual delivery of the Churchill and Nelson rivers to Hudson Bay from open-water season to the ice-covered months of November to May.

Perhaps the most dramatic effect of regulation on the lower Nelson River flows is that seen in the day-to-day regime. At Kettle Dam, for the period 1979 to 1988, most of the day-to-night drops in hourly mean discharge were over 2000 $m^3 s^{-1}$ in winter, and were commonly almost 3000 $m^3 s^{-1}$ in summer. Short-term fluctuations can have a dramatic effect on the ice cover. In particular, under-ice currents can result in thin ice that diminishes the strength and stability of the ice cover, affecting over-ice trafficability for both man and animals. Upstream, at Kelsey and Jenpeg dams, such large day-to-day fluctuations never occurred.

Lake surface areas have also changed significantly as a result of the LWCN project. In Cross Lake, 300 km^2 of lake bottom were intermittently dewatered by the seasonal fluctuations in water levels; while three of the larger lakes along the lower Churchill River - Partridge Breast, Northern Indian and Fidler - have been reduced in area by 39 to 76%. Along the Churchill River Diversion Route and the lower Nelson River, new lakes (reservoirs) have been created and others greatly increase in area; for example, Southern Indian Lake increased in area from 2082 km^2 to 2377 km^2, Notigi Reservoir, with an area of 733 km^2 was created by the extensive flooding of a series of small lakes with a pre-project area of 182 km^2, and Kettle Dam created the new 288 km^2 Stephen's Reservoir.

The water quality in the FEMP study area, during the 1987 - 1989 FEMP study period, generally met the Canadian Water Quality Guidelines for drinking water, recreational uses, and protection of aquatic life, although there were some exceptions. A number of significant changes occurred in the water quality since the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project, many of which could be attributed to the mixing of water masses from different sources or to changes in shoreline stability.

From January 1987 to October 1989, 61 water quality variables, including physical data, ions, nutrients, metals, and biological data, were measured at 11 sites, on regulated and natural rivers in the FEMP study area.

Canadian Water Quality Guidelines, established in 1987, were used as a means for assessing the water quality in the FEMP study area. Major uses of water for which Guidelines have been developed include drinking water, recreational use and the protection of aquatic life. Variations in environmental conditions across Canada will affect water quality in different ways; hence, many of the Guidelines may need to be modified according to these local conditions. The use of the Guidelines for assessing adverse effects in the FEMP study area is limited in that they have not been established for all variables, they are not based on site-specific cause and effect studies in northern Manitoba, and they do not take into account the effect of cumulative stresses caused when the values of two or more water quality variables simultaneously exceed the guideline values. They are thus a suggestive, rather than a definitive, basis for assessing adverse effects in the FEMP study area.

Mean turbidity levels exceeded the Canadian drinking water guideline and mean extractable aluminum (Al) and total copper (Cu) exceeded the aquatic life guidelines at all sites. Mean extractable iron (Fe) exceeded the drinking water and aquatic life Guidelines at all 3 natural sites, at sites along the Churchill River Diversion (CRD), and at the outlet of Split Lake. The high levels in Split Lake appear to be a direct result of CRD; mean extractable Fe was below the Guidelines in the Nelson River at sites upstream of Split Lake and in the Jack River. Similarly, there were sporadic occasions when the aquatic life guidelines were exceeded for total lead (Pb), cadmium (Cd), and zinc (Zn) in the natural rivers and at sites on the CRD, but never in the Jack River or the Nelson River upstream of Split Lake. Total lead (Pb) occasionally exceeded the aquatic life guideline at the outlet of Split Lake, although these occasional high levels are not directly attributable to CRD. Two of the natural rivers (Burntwood River above Threepoint Lake and Footprint River above Footprint Lake) were distinguished by considerable stability in water quality between the 1972 - 1973 pre-development sampling period and the 1987 - 1989 FEMP study. There were no significant changes in the 17 variables for which comparable pre- and post-development data existed due to any cause other than a change in analytical methodology. At the third natural site, the Aiken River, lack of pre-development water quality data precluded an analysis of temporal trends.

At the Rat River above Threepoint Lake, there was a 3-fold increase in turbidity caused by bank and shoreline erosion. Other significant changes, such as decreases in hardness and alkalinity and increases in sodium and potassium, were directly attributable to diversion and were a reflection of differences in water quality between the Churchill River and the pre-existing Rat River. In most cases, the changes were no greater than the difference in concentrations between the Rat and Churchill rivers. The two exceptions were a larger than expected decrease in total organic carbon (TOC) and no change in the phosphorus (P) concentration in the Rat River following diversion, despite the lower concentration in the Churchill River. The mechanism for the loss of TOC remains to be determined. The lack of a decrease in P was attributed to the continued release of P from flooded soils and vegetation. Impacts of diversion on water quality in the Burntwood River at the outlet of Threepoint Lake, the other FEMP site in the Nelson House area, could not be quantified due to the lack of pre-development data. It is likely that changes at this site would be qualitatively similar to those in the Rat River, except for a smaller impact on turbidity.

The Burntwood River at Thompson site had the most extensive water quality database of any site in the FEMP study area. Although most of the changes in water quality did not occur until after the autumn of 1977, when the diversion was fully operational, several changes were evident during the CRD construction, when Rat River flows were cut off at the outlet of Notigi Lake (e.g. an increase in turbidity and hardness) or during the immediate post-diversion period, as flows were gradually increased (e.g. an approximate doubling of P concentrations between the construction and immediate post-impoundment periods, with a return to pre-development levels by 1987). Significant water quality changes between the pre-development and FEMP study periods included decreases in hardness, alkalinity and dissolved calcium (Ca). These decreases were due to the introduction of softer Churchill River water. An approximate doubling of turbidity was attributed to bank and shoreline erosion along the Burntwood River below Threepoint Lake.

Impacts of the LWCN project on the water quality at the two FEMP sites in the Outlets Lakes area, Sea River Falls and Jack River, could not be assessed because of the lack of pre-development data.

No quantitative assessment of water quality changes at the Burntwood River inlet to Split Lake since CRD was possible due to the lack of pre-development data; however, it is likely that changes at this site caused by CRD were similar to those documented upstream at Thompson. Several significant differences in water quality were noted at the Nelson River inlet to Split Lake between the 1971 - 1974 pre-development and the 1987 - 1989 FEMP study periods, but none of these changes could be directly attributable to the LWCN project. The very low Nelson River flows during the entire FEMP water quality study period, caused by drought conditions in western Canada, could have caused, or substantially contributed to, the observed changes.

Statistical analysis of pre- and post-development data at the outlet of Split Lake revealed significant declines had occurred in a number of variables, e.g. hardness, conductivity, calcium, potassium, etc. These decreases were a direct result of the diversion. It is interesting to note that a significant increase in annual mean water turbidity or suspended sediment concentration (NFR) was not observed, nor a decrease in water transparency, despite the much higher suspended sediment concentrations in the Burntwood River than in the Nelson River. Much of the suspended sediment load of the Burntwood River appears to settle out near the mouth, preventing a general increase in suspended sediment levels in the lake or downstream. An increase in extractable Fe was inferred, such that the annual mean concentration at the outlet, from 1987 to 1989, exceeded the Canadian Water Quality Guidelines by 30%. This increase, and significant decreases in total dissolved arsenic (As) were inferred on the basis of current differences in concentration between the Burntwood and Nelson rivers and the relative contribution of these rivers to total inflow at Split Lake.

Studies of fecal coliform levels in the recreational waters of the 5 Northern Flood Committee (NFC) communities indicated that contamination was not a significant concern. No clear evidence of contamination was found at any site, including the vicinity of sewage treatment plant outfalls where contamination might be expected. However, the limitations of the sampling program with respect to the number and frequency of samples prevent concluding that fecal coliform levels comply with Canadian Water Quality Guidelines.

The water quality - water discharge relationships and the seasonal variations in water quality were examined to further assess the impact of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Hydroelectric Project on the water quality in the FEMP study area. With several important exceptions, the water quality - water discharge relationships derived from the FEMP study data offered limited potential for impact prediction or management. A number of distinct seasonal trends were evident in the comparison of water quality under *ice-cover and in the open-water season during the 1987 - 1989 FEMP study period; however, while several apparent changes in seasonal patterns were noted, none could be conclusively attributed to the LWCN project.*

The strongest water quality - water discharge relationship correlations were found at sites where there is the least need for their application, i.e. the natural rivers and the Nelson River at Sea River Falls. Most relationships at sites on the Churchill River Diversion (CRD) were too weak to have much predictive ability although there were several important exceptions, including the relationships for non-filterable residue (NFR) and turbidity in the Burntwood River at Thompson and for turbidity and alkalinity in the Burntwood River at the inlet to Split Lake.

The natural rivers, sites on the Nelson River upstream of Split Lake, and impacted sites prior to development were characterized by having many discharge-correlated variables, with negative correlations dominating (e.g. sodium, potassium, chloride, hardness, etc.). The discharge relationships at sites along the CRD, however, were profoundly different. In the Rat River above Threepoint Lake and in the Burntwood River below Threepoint Lake, at Thompson, and at the inlet of Split Lake, all correlations with discharge were positive following diversion. This is evidence of the increased importance of eroded shoreline materials in regulating water quality. Whereas water quality typically was highest during periods of peak flow prior to diversion, water quality now decreases with increasing river flows.

A similar shift from negative correlations prior to development to positive correlations during the FEMP study was evident in the Nelson River at the outlet to Split Lake as well. Although consistent with the changes in the discharge relationships in the Burntwood River following CRD, these changes at the outlet of Split Lake cannot conclusively be attributed to the diversion. Similar changes in the discharge relationships in the Nelson River at the inlet to Split Lake suggest a possible influence of the low Nelson River flows during the FEMP study or possibly some impact of the LWCN project in the upper Nelson River area.

Distinct seasonal trends that were evident included lower chlorophyll a concentrations under ice cover at several sites (e.g. Jack River, Burntwood River at Thompson, and the inlet to Split Lake) and elevated nitrite-nitrate (NO_2-NO_3) concentrations under ice cover at most sites. These trends might have been the result of the imposition of light limitation on algal growth by accumulated snow and ice cover and a lower photosynthetic demand for nitrogen at the lower light levels and cooler temperatures under ice cover.

A variety of other variables displayed marked seasonality at specific sites, with more seasonally variant parameters in the smaller natural rivers than in the larger Burntwood, Rat and Nelson rivers. Most of these variables (e.g. major ions, conductivity, hardness, and in some cases metals) increased under ice-cover, although NFR was typically lower in winter. For variables that were correlated with discharge, these seasonal differences were accounted for by seasonal variations in river discharge.

An examination of changes in seasonal patterns related to the LWCN project was restricted to a qualitative analysis because of the limited pre-development, under ice-cover data and by the few variables that were common to the pre- and post-development periods at many sites. Several apparent changes in seasonal patterns were noted, but none could be conclusively attributed to the LWCN project. For the site where the most complete analysis was possible, the Burntwood River at Thompson, only chlorophyll a showed marked seasonality in any of the pre-development, construction, or FEMP study periods.

Sediment and Morphology

Changes in the hydrologic regime in the FEMP study area have substantially altered the shorelines of the lakes and rivers. Characterization of shorelines has been limited, both temporally and spatially, and in terms of providing required input to assess related changes, such as sediment sources, access problems, etc.

The focus of the FEMP sediment and morphology investigations was the CRD area where the most dramatic changes in the shorelines within the FEMP study area occurred, following the LWCN project. These investigations consisted of: 1) a review of all relevant literature; 2) feasibility studies to assess morphological changes, using air photos and Landsat images; and 3) preparation of a sediment budget.

The only previous shoreline classifications conducted in the FEMP study area were based on a scheme developed as part of the LWCN study in 1975. This scheme was of limited usefulness in classifying post-project shorelines, and in particular shoreline changes from pre-project conditions, because it did not include such post-project shoreline features as inundated vegetation, floating organic material, cleared shorelines, or riprap. Consequently, a feasibility study was conducted under FEMP to assess the usefulness of air photo interpretation in analyzing shoreline features.

The results of the feasibility study showed that it was possible to quantitatively estimate changes in the shorelines. For example, from an analysis of 1972 and 1985 air photos for Footprint Lake and Honeymoon Lake, a small lake connected by flooding to Footprint Lake, located southeast of Nelson House, it was estimated that the length of shorelines for these lakes containing standing debris increased from 0.2 km to 56 km and that 37% of the total post-diversion shorelines contained standing debris. Changes that have occurred in the shorelines of these two lakes are typical of the changes in many other CRD lakes. Quantification of the shoreline characteristics of these lakes, and of the changes to them, could also be undertaken using air photo analysis.

Most of the morphological changes that have already occurred have not been quantified. A FEMP pilot study was conducted that provided rough estimates of shoreline erosion and sediment production at key locations along the CRD route.

Previous studies had identified approximately 20 "erosion hot spots" along the CRD i.e. areas of localized active shoreline erosion; however, there had been no estimates of the areas or volumes of material eroded at these sites. Under FEMP, a pilot project was initiated in which a series of comparative analyses of air photos generated data on the displacements in shoreline positions; these data, coupled with topographic data, were used to provide a rough calculation of the volume of material eroded at some of the previously identified erosion hot spots.

For example, one such area that was part of this pilot project was a small island near the southern shore of Footprint Lake, immediately east of the Footprint River. Based on a comparison of 1972 and 1985 air photos, this island's area was found to have decreased by approximately 6200 m^2, while the shoreline perimeter decreased by 170 m. On the assumption that 50% of the shoreline recession was due to erosion (rather than inundation) and that the depth of eroded sediment was 2 m, the total volume of material removed from this site was estimated to be 6000 m^3 or 27 m^3 per metre of present shoreline length. Estimates of material that has eroded from other sites along the CRD were generated in a similar manner; high and low estimated values were based on different assumptions of eroded versus inundated areas and on different assumed bank heights.

Rough estimates of erosion rates ranged from approximately 6 m^3 per meter of shoreline from low-lying sites to somewhat slower rates of shoreline retreat for shorelines with much higher bank heights. However, given the larger amount of material which must be eroded from these higher relief sites, the inferred slower rates of bank retreat do not necessarily mean that smaller volumes of sediment are being produced from these areas. Material characteristics and orientation of the shore in relation to the prevailing wind direction are important determinants in the rate of bank retreat.

In general, erosion to date has not been nearly as serious along the CRD as was predicted in pre-diversion studies. For example, sediment delivery to Split Lake from the CRD is estimated at slightly less than 1 million tonnes/year; while this amount is approximately 10 times pre-diversion levels, it is much less than the projected estimates of 6 million tonnes/year.

It might be overly optimistic, however, to assume that erosion rates will necessarily diminish in the near future. As sites erode, an increasing length of bank tends to be exposed so that volumetric rates of erosion could increase with time, even if the rate of bank recession slows down. Also, if gradual river bed degradation is proceeding at some points, banks that appear stable may eventually be undermined and begin to crumble. (The extent to which this may be occurring is unknown, as only one cross section along the CRD has ever been resurveyed.) On the other hand, initial erosion at some sites can slow or stop as bedrock is reached. It thus appears that projection of future erosion rates and quantities of sediment subsequently generated are subject to considerable uncertainty and could not be improved substantially without extensive field studies.

There have been documented changes in the sediment regime along the Churchill River Diversion (CRD) route. Completion of the FEMP sediment budget will provide additional insight into these changes.

Active shoreline erosion along the CRD route has increased sediment production, some of which is redeposited near shore and some of which is transported to be redeposited further downstream. Pre-FEMP studies conducted by DFO of the sediment regime of Southern Indian Lake (SIL) showed that eroded sediment was temporarily redeposited near shore and then subsequently remobilized to become part of the lake's general suspended load. The increased input of sediment into SIL resulted in increased bottom deposition, increased sediment concentrations, and increased sediment output, which was mostly transported to and redeposited in the upper Notigi Reservoir.

Notigi Reservoir is thought to be acting as a sediment sink, with the upper portion trapping most of the sediment output from SIL and the lower part showing sediment deposition resulting from local shoreline erosion. Turbidity measurements taken under FEMP in 1987 were significantly greater than those measured in the late 1970s, suggesting that shoreline erosion in the lower part of Notigi Reservoir may be increasing, perhaps facilitated by the decay and removal of the inundated vegetation.

There are a number of actively eroding sites between Notigi Reservoir and Thompson; unfortunately, data on changes in sediment production in this reach are limited. There is, however, a good data base at Thompson. Turbidity briefly returned to pre-development levels, at Thompson following the LWCN construction period, but has since increased significantly. Of particular interest is the apparently increased incidence of higher turbidity levels at Thompson, i.e. turbidity levels in post-project years are higher for a greater proportion of the year than in pre-project years. Although it is not known how representative the Thompson site might be of the rest of the CRD with respect to this apparent change, its location downstream of some of the major erosion sites along the CRD may make it a good indicator site.

A large amount of sediment, most especially from the lower reaches of the CRD route, has been transported and deposited in Split Lake. No studies of sedimentation rates have been conducted in Split Lake; however, on the basis of turbidity measurements and analyses of satellite images, it appears that most of the sediment has been deposited near the Burntwood River inlet forming a subaqueous delta.

All sediment data, including historical and other non-FEMP data, have been carefully reviewed, standardized, and incorporated into the preparation of a sediment budget for the CRD route; this budget is expected to be available later in 1992.

Mercury

A mercury duration model was developed based on rates of methylation and demethylation observed in reservoirs of various ages, located primarily in northern Manitoba. This model indicated that there will be a slowly accelerating rate of decline in the net production of methyl mercury over time, with levels returning to estimated pre-development levels approximately 80 years after impoundment.

Mercury in fish is primarily in the form of methyl mercury. The production of methyl mercury is controlled by the net result of two opposing bacterial processes – the methylation of mercury and the demethylation of methyl mercury. Measurements of mercury methylation (M) and demethylation (D) rates in sediments from reservoirs ranging in age from 10 to 60 years were made, along with the M and D rates in a non-flooded control lake, which was used as a surrogate for pre-development or "normal" M/D conditions. The plotted data indicated that the half life (i.e. the period required for a 50% reduction) of the elevated M/D balance in the FEMP area was an estimated 60 years; an additional 20 years would be required before levels would return to pre-development values.

The validity of the mercury duration model as a means of predicting the rate of decline of mercury levels in fish was evaluated by overlaying pike and walleye mercury data on the predicted M/D decline curve. Data on mercury in fish were selected from reservoirs with similar characteristics (e.g. similar extent of flooding). There was good agreement between the predicted elevation of M/D in a reservoir of given age and the measured mercury concentrations in fish.

It is important to note that it is not the age of the reservoir per se that is the critical factor in determining mercury levels in fish, but rather the relative availability of fresh organic matter (i.e. the amount and type of vegetation flushed into the water). The model's prediction of a decline in the M/D balance over time was based on a decline over time of the availability of organic matter. This point was clearly illustrated in the case of Sipiwesk Lake.

The M/D sampling of Sipiwesk Lake in 1987 revealed higher mercury levels than would have been expected given the age of this reservoir (flooded in the early 1960s). It was postulated that the way in which this reservoir is regulated determined the unexpectedly high M and D rates. Since the operation of Jenpeg dam in 1976, Sipiwesk Lake levels have been low in summer and high in winter, the reverse of most hydroelectric reservoirs. Recolonization by fast growing vegetation of the drawdown zone in summer and the subsequent flushing of this material into the lake during periods of high water is probably providing a continuous source of fresh organic matter, thus stimulating ongoing mercury methylation.

FEMP mercury studies confirmed that the availability of organic material, not the total mercury concentrations in water, was the most important factor affecting the net production of methyl mercury in northern Manitoba reservoirs. Oxygen conditions in the sediment and inorganic sediment deposition were other relevant factors.

Earlier studies conducted in the FEMP study area, under the Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion (CMMA), concluded that the single most important factor affecting net methyl mercury production was the amount and type of flooded organic material. This conclusion was confirmed by the FEMP mercury studies, as evidenced, for example, by the results of a sampling program in Methyl Bay, Southern Indian Lake, in 1986. Considerable variation in methylation activity that was evident among three near shore (flooded) sampling sites was found to be the result of substantial differences in sediment organic content among the sites.

The CMMA study had also concluded that there was no evidence that flooding had caused an increase in mercury concentration in water in any of the reservoirs studied. This conclusion was based on measurements of mercury levels in plankton; this surrogate method of measuring mercury levels in water was necessary because the best analytical methods then available were not sensitive enough to detect very low levels of mercury in water. Improvements in analytical methods since the completion of the CMMA study enabled the direct measurements of total and methyl mercury concentrations in water in the FEMP mercury studies. It was found that while total mercury concentrations in water were not higher in reservoirs than in Granville Lake, the reference lake, methyl mercury concentrations were. Mean total mercury concentrations ranges from 1.07 $ng{\cdot}L^{-1}$ (Notigi West, 1989) to 2.10 $ng{\cdot}L^{-1}$ (Thompson, 1989); mean methyl mercury concentrations ranged from 0.017 $ng{\cdot}L^{-1}$ (Methyl Bay, 1989) to 0.054 $ng{\cdot}L^{-1}$ (Stephens Lake, 1989). These values were substantially below the upper limit of the Canadian Drinking Water Guideline for total mercury levels in water of 1000 $ng{\cdot}L^{-1}$.

FEMP investigations of the major metabolic groups of bacteria responsible for methylation (M) and demethylation (D) found that methanogens and sulphate reducers jointly accounted for all of the M and D activity in the flooded zone of Methyl Bay and the majority of the M and D activity in Granville Lake. The finding that the same bacterial groups were responsible for both M and D indicates that it may be difficult to develop mitigative measures based on the selective inhibition of the methylators or stimulation of the demethylators. However, the finding that oxygen availability did not significantly influence demethylation rates offered a partial explanation for the differential stimulation of the methylation over demethylation: low oxygen levels favoured for the methylation process are common in flooded sediments.

Another relevant factor in the mercury problem, and in particular one which may affect the duration of the mercury problem, is sediment deposition. For example, a small but significant decline in mercury in northern pike in Rat Lake (from 1.35 to 1.20 $g.g^{-1}$) occurred in the late 1980s, a time coincident with an increase in shoreline erosion. It is postulated that organic matter was covered with inorganic sediment thus effectively preventing the stimulation of microbial methylation. It must be stressed that it is sediment deposition, and not sediment resuspension, which is suggested as a possible mitigating factor. Tests conducted under the CMMA showed that increased suspended sediment concentrations did not significantly reduce mercury concentrations in fish and, in some cases, caused slight increases.

Mercury levels in whitefish from all lakes sampled in the FEMP study area were below the Canadian guideline of 0.5 ppm; mercury levels in pike and walleye varied considerably between lakes and over time with levels in many cases being above 0.5 ppm. The majority of the people sampled from the six native communities in the FEMP study area had levels in the 0 - 20 ppb level, which is considered normal, with virtually all of the remaining values being less than 80 ppb. A few women of child-bearing age in four of the six communities, notably South Indian Lake, had mercury levels between 20 and 80 ppb.

Mercury levels in fish from eight major lakes in the FEMP study area were measured in the mid - to late - 1980s either under the auspices of the FEMP or as part of a concurrent program conducted by the Manitoba Department of Natural Resources; these data extended the historical record of a number of lakes that had previously been sampled under the auspices of the CMMA. While mean standardized mercury levels in whitefish were below 0.5 ppm in all lakes sampled, only the walleye and pike in Cross Lake and the pike in Split Lake had mean standardized mercury levels below 0.5 ppm. Mean standardized mercury levels in walleye in Split Lake hovered around the 0.5 ppm mark, ranging from 0.42 to 0.61 ppm. Mean standardized mercury levels for pike and walleye from Southern Indian, Issett, Sipiwesk, and Stephens lakes ranged from 0.5 to 1.0 ppm, and those from Rat and Threepoint lakes ranged from 1.0 to 1.5 ppm.

A number of conclusions can be drawn from an examination of the complete data record - current and historical. Predatory fish from the most extensively flooded lakes had the highest mean mercury concentrations; after more than a decade since flooding, these fish still had mercury levels too high to permit their being sold anywhere in the world. Some significant declines in mean mercury concentrations have been recorded in recent years. For example, the mean mercury concentration in walleye in Rat Lake declined from 1.92 ppm in 1984 to 1.09 ppm in 1989; however, even with such declines, mean mercury concentrations in predatory fish are still generally much higher (e.g. 2 - 4 times higher) than estimated pre-development levels. Large variability in the mercury concentrations of individual fish still exist; for example, mercury concentrations in pike in Issett Lake in 1988 ranged from 0.15 ppm to 2.67 ppm. Such variability is due, at least in part, to variability in the size of fish. Collectively, these findings reaffirm the conclusion of the CMMA that mercury concentrations in fish vary according to species, size of fish, lake of origin, and length of time since the lake was flooded.

Mercury levels in the residents of the six native communities within the FEMP study area continued to be tested by Health and Welfare Canada. During the late 1980s, all values were below 80 ppb, with the exception of one individual in South Indian Lake whose level was between 80 and 100 ppb; the majority of the values were less than 20 ppb, the level which is considered "normal" for adults. A few women of child bearing age in four of the six communities, most notably South Indian Lake, had values between 20 and 80 ppb. Values greater than 20 ppb for women of child bearing age are a concern because of the uncertainty of the risk of mercury exposure to the fetus.

Health and Welfare Canada's mercury program began in these communities in the late 1970s. An examination of the full data record showed that, in general, mercury levels in people have been highest in the residents of South Indian Lake and Nelson House, followed by the levels in people from Split Lake and York Landing; the lowest mercury levels have been recorded in people from Cross Lake and Norway House. A number of factors make it difficult to assess trends in mercury levels: 1) large variability in the number of community residents tested each year; 2) no identification in the published data record of values from the repeated testing of the same individuals; and 3) annual reporting of test results, which obscures any seasonal patterns.

As was evidenced in the interviews conducted for "Changes", the FEMP videotape, the elevated mercury levels in fish have caused concerns about possible health consequences among the residents of the six native communities in the FEMP study area. As a result, there appears to be a loss of confidence in fish as a healthy staple in their diet; some people noted that they are either more cautious about the source of their fish and/or that they have reduced their fish consumption. There is also a concern about the possible impact of further developments (e.g. Wuskwatim Dam) or remedial measures (e.g. Cross Lake weir) on future mercury levels in fish.

Fisheries and Aquatic Life

The biological status of the Southern Indian Lake (SIL) whitefish fishery has improved since the immediate post-impoundment period, but has not re-

turned to pre-impoundment conditions. Additional monitoring would be necessary to determine whether the whitefish fishery ultimately recovers or stabilizes at levels lower than pre-impoundment values. A study of pike in Wupaw Bay, an isolated bay of SIL, suggested that they have also been negatively affected by post-impoundment changes.

The commercial fishery at SIL was the largest in northern Manitoba prior to impoundment; about 333,500 kg of fish were taken yearly. Approximately 85% by weight of the commercial catch was composed of whitefish; the rest was made up of pike and walleye. A reduction in grade, and consequently in price, and a reduced catch per unit effort (CPU) led directly to the collapse of the commercial whitefish fishery at SIL following impoundment. Two FEMP studies assessed the current status of the whitefish population at SIL; a third FEMP study, reinvestigated the pike population in Wupaw Bay, an isolated bay in the south west portion of SIL.

Grade is a major determinant of price for whitefish; for example, the price of an export grade whitefish can be double that of a continental grade. Grade classifications are based on the number of cysts of the parasite *Triaenophorus crassus* per 45 kg of whitefish (dressed weight). Grade classifications are as follows: export grade, 0 to 40; continental grade, 41 to 80; and cutter grade, over 80.

Historically, SIL was an export grade whitefish fishery; however, in 1982, the lake was downgraded to continental grade. The average cyst count for fish sampled under the FEMP study in 1987 was 51.9 from Region 4 (historically, the most important commercial fishing area of SIL), 74.1 from Region 5 (currently, an important commercial fishing area), and 81.1 for the southern portion of the lake. Cyst counts, in 1987, for sub-areas in Region 4 were: 59.9 for Region 4A; 21.3 for Region 4B (small sample size); and 64.1 for Region 4C. Analysis of cyst counts by whitefish external colour showed that the chance of a light-coloured whitefish (the preferred colour) being export grade was only 48%. Thus, it appears that neither selective fishing by sub-area of Region 4 or by colour for light-coloured whitefish would likely result in a reclassification of the commercial catch from continental to export. However, it should be noted that Region 4 still produces export fish in significant quantities and has the best quality of the lake regions sampled. Moreover, sub-Region 4B may still have retained its export grade status.

CPU in 1987 for Region 4 (8.44) and Regions 4 and 5 combined (9.75) was still depressed in comparison to pre-impoundment levels (e.g. the 1972 value was 23.1). A number of factors can affect CPU such as the fouling of nets with debris and/or non-commercially valuable rough fish that reduce the amount of commercially valuable species caught and increase net cleaning time. An increase in the frequency of net relocation (which may be necessary due to net fouling) increases fishermen effort. The number of days nets are left in one location has been reduced from a pre-impoundment average of 18 to an average in 1987 of 6.3 in Region 4 and 5.0 in Region 5.

The main factor affecting CPU, however, is the abundance of fish and their movements. The results of an age analysis conducted as part of the FEMP study suggests that SIL is a light to moderately exploited commercial whitefish fishery; this low level of commercial exploitation would render unlikely an hypothesis that considers over-fishing as a casual factor in the decreased levels of CPU on traditional fishing grounds. Bodaly et al.(1984) showed an absence of genetic differences in whitefish in SIL after impoundment compared to the presence of at least 3 genetically distinct whitefish populations prior to impoundment. This suggests a post-impoundment mixing of stocks within SIL. Emigration of whitefish from SIL was suggested as an important cause of the post-impoundment decline in CPU (Bodaly et al. 1984 b); this suggestion was pursued under FEMP by an investigation of the whitefish populations immediately downstream of Missi Falls.

Large numbers of fish were caught below Missi Falls in 1986 and 1987; whitefish dominated the catch in nearly all samples. Estimated numbers of whitefish reached a high of 88,764 in September, 1986. The seasonal distribution of whitefish at Missi Falls was variable and depended on environmental conditions. In 1986, a year when the mean discharge from June to August approximated that of pre-impoundment conditions, the number of whitefish was highest in the autumn. Most of these fish, which were in good condition, appeared to have originated from SIL. It was concluded that these fish were trying to return to SIL to spawn. In 1987, a year of lower flows and higher water temperatures than 1986, the number of whitefish was highest in the summer. Most of these fish appeared to have originated from the lower Churchill River lakes downstream of Missi Falls and were in poorer condition than the 1986 fish (e.g. they had significantly thinner bodies and a higher incidence of empty digestive tracts). It was concluded that they were trying to escape the warmer waters of the downstream lakes. Thus, it would appear that the Missi Falls Control Structure was blocking normal seasonal migrations of whitefish into and out of SIL and that this was a cause of the reduction in CPU in the SIL whitefish fishery.

Northern pike can be an important part of the SIL fishery (as discussed in the next section); they are also important as the final host in the life cycle of the parasite *Triaenophorus crassus*. A study of the northern pike population dynamics that was begun in 1976 in Wupaw Bay, SIL, a bay that is not completely typical of much of post-impoundment SIL, was extended to 1988 under FEMP. A downward trend in CPU and in condition factor indicate that the adult northern pike population in Wupaw Bay has suffered since lake impoundment. The decline in northern pike was attributed to post-impoundment changes, such as increased water depth, which rendered Wupaw Bay habitats less suitable for pike.

Shiners are an important component of the adult pike diet in Wupaw Bay. Beginning in 1981, the relative abundance of emerald and spottail shiners changed noticeably; this change was due to an increase in emerald shiners rather than a decrease in the number of spottail shiners. Habitat changes thus appear to have favoured the pelagic emerald shiner, relative to the more littoral species, such as the spottail shiner.

In summary, studies of the SIL whitefish fishery and the more geographically-limited pike study showed that these populations had been adversely affected both in terms of quantity (reduced CPU) and in quality (lower grade or poor condition). The whitefish fishery may be showing marginal improvement or stabilizing at levels lower than pre-impoundment values (e.g. an improved CPU since the immediate post-impoundment period); however, grade analysis of the whitefish catch suggests that it may not be possible to return to an export quality fishery. The pike population in Wupaw Bay has not shown any signs of recovery. Additional data for subsequent seasons would be needed to assess the longer term status of the SIL whitefish and Wupaw Bay pike.

A study of the economic performance of the commercial fishery at Southern Indian Lake (SIL) in 1988 showed that the fishery is now financially viable; however, approximately 36% of the revenue to the fishery came from a compensation fund and from a provincial freight subsidy program. The average income per firm increased 32% from $6,299 in 1980 (in 1988 dollars) to $8,289 in 1988.

Since the inception of a commercial fishery at SIL in 1942, it has been a major component in the economy of the South Indian Lake community. For example, prior to impoundment (1972), it was estimated that the fishery provided 43% of the community's income, making it the single most important source of livelihood in the community. However, following impoundment the commercial fishery collapsed.

Under FEMP an evaluation was undertaken of the economic performance of the SIL fishery in 1988. Three approaches were used in this evaluation: 1) determination of average net incomes, using the same methods as those in a 1980 study; 2) an alternative analysis that more closely reflected the fishermen's view of the economics of the fishery (e.g. loan payments instead of depreciation and interest amounts on boats and motors); and 3) an estimation of the total community income from the fishery.

A comparison of the 1988 average income per firm of $8289 (which included revenues from a compensation fund and from a provincial freight subsidy program) to the 1980 average income per firm of $6299 (in 1988 dollars) showed an increase of 32% in real income. This increase was the result of factors which affected both price and cost. Whitefish prices are extremely important to a northern lake, like SIL, that is remote from southern markets; an examination of whitefish prices and output for SIL since 1982 showed that output followed closely the average price per kilogram. In 1988, a year when whitefish prices were relatively high, there was a significant increase in catch per firm. There was also a reduced replacement rate for capital items in 1988, which may have been due to a reduction, since 1980, of debris in the water resulting from flooding.

There have been a number of changes in the SIL fishery since 1980: 1) a reduction in the mesh size legally allowed for the harvesting of whitefish; 2) a shift in fishing intensity from Region 4 of SIL to Regions 4 and 5; 3) a change in the administration of the SIL compensation fund; 4) the provision of financial assistance to fishermen utilizing outlying lakes; and 5) the introduction of regular ferry service to the community in 1985.

Although fishermen had been operating in the southwest region of the lake for some time, it appears that the ferry service has increased participation in the fishery in this part of SIL. Although CPU was greater in the north end (in the order of 25 tubs for every 20 nets set versus 8 to 10 tubs in the region near the community), only 9 of the 23 firms sampled in 1988 delivered their catches to Missi Falls. Average income per firm in the northern region of SIL was $13,754 versus $4,776 for those firms delivering to the South Indian Lake community. Greater distance from the community and rougher waters require a greater commitment to the fishery in the northern portions of the lake, whereas the south end attracts more families, elderly people, and novice fishermen.

Results of the other two economic evaluations of the SIL fishery more closely approximated the real economic value of the fishery to the community fishermen and to the community in general. In addition to the difference in assessing the cost of capital items, the alternative analysis of firms' net incomes also considered estimated UIC benefits; this alternative calculation was significant because it more closely reflected the net cash income that was received by the fishermen. Under this method, the average net income per firm was $9,751.

Using the data generated from the sampled firms, which represented over 80% of the active licensed fishermen in the study area, the total community income from the fishery was estimated to be $232,326; if the wage labour paid out by the firms is added back in, the total net income to the community rises to $242,631. In addition to the cash income from the fishery, the community also benefited from a substantial amount of food from the fishery. Not only was a large quantity of fish consumed in the community but the fishermen were able to shoot moose while on the lake fishing. Rough estimates of the economic value of amount of fish consumed (30 to 60 kg per capita), and moose harvested (20) added an additional $166,000 to $286,000, giving an estimated total value of $398,326 to $518,326 of the commercial and subsistence fisheries of Southern Indian Lake.

In summary, the economic evaluation of the SIL fishery in 1988 depended upon the point of view used (e.g. firm or community) and on the method of calculation. The fishery seems secure from a financial point of view; however, it should be noted that the revenues from a compensation fund and a provincial freight subsidy program were included in all calculations.

Preliminary analysis indicate that the genetic structure of the whitefish stocks in Playgreen Lake and the northern basin of Lake Winnipeg has not changed since the construction of the Lake Winnipeg regulation (LWR) project. Further analysis will be required to confirm or contradict this preliminary finding.

In response to claims by Playgreen Lake fishermen that the spatial distributions and seasonal movements of separate stocks of whitefish in the northern end of Lake Winnipeg and Playgreen Lake have changed since LWR, an investigation was initiated of the genetic structure of these populations. A fish stock is, by definition, a population that shares a common environment and gene pool. This definition implies a degree of reproductive isolation between various stocks of a particular fish species in a particular area; this reproductive isolation will generally be expected to result in genetic differences between stocks, which will tend to accumulate due to random genetic drift and/or selection. The genetic differences expected among various stocks of fish and the environmental differences expected in their habitats have allowed the application of methods to identify and differentiate stocks.

Direct assessment of genetic differences is possible by a number of means, the most common of which is the electrophoresis of isozymes. This method was used in a FEMP study to compare the genetic stock of the whitefish population in 1989 to the genetic stock structure that was present in 1975.

The results of the analysis indicated that at least two different stocks of whitefish exist in the northern Lake Winnipeg/Playgreen Lake areas. One stock uses sites in the north basin of Lake Winnipeg for spawning and the other utilize Little Playgreen Lake for spawning. The same genetic similarities and differences among stocks were found in 1975, before LWR, and in 1989, after LWR. The preliminary results of this study, therefore, do not provide support for the observations of commercial fishermen on Playgreen Lake that the population structure of whitefish may have changed due to LWR construction and operation. This conclusion is tentative and preliminary, however, for a number of reasons.

First, the analysis was based on only a limited genetic comparison; further genetic analyses should be undertaken as genetic models are refined and a more extensive data set is interpretable. Second, an analysis of morphostaging dabblers and to a lesser extent divers. Higher duck densities observed in the September 26, 1988 survey of Notakikwaywin Lake, a lake unaffected by the CRD, than in the affected lakes surveyed supports this hypothesis. The apparent reduction in waterfowl availability, combined with boat navigation and access problems, have limited opportunities for Nelson House Band members to view and hunt waterfowl.

Surveys of ducks and geese conducted in the Norway House area in September 1986 and October 1987 showed considerable variation in numbers, depending on species, lake, and date of survey; but as a rule, numbers were generally low. Data are too limited, both temporally and spatially, to estimate changes in the level of waterfowl use of this area with any degree of confidence. The data suggest, however, that there may have been a decline in diving duck use of this area following the regulation of Lake Winnipeg.

A series of five low-altitude aerial surveys were flown over parts of the Outlet Lakes area, including 8-Mile Channel and Playgreen, Kiskitto, and Kiskittogisu lakes. Comparison of the results of the 1986/1987 survey with the 1972/73 survey conducted as part of the Lake Winnipeg, Churchill, Nelson (LWCN) Rivers Study showed a decline in diving ducks of approximately 96%. It is risky, however, to draw broad conclusions about diving duck numbers on the basis of the 1972/1973 and 1986/1987 surveys, because both surveys provide only a limited number of "point-in-time" counts. Furthermore large between-year changes are not uncommon in waterfowl counts derived from aerial surveys. The data suggest that the Outlet Lakes area did not attract large numbers of dabbling ducks in either of the two survey periods. Similarly, only relatively small numbers of Canada geese were observed on individual surveys in both survey periods; indeed, no geese were observed on several surveys.

The only other available data for this area are annual breeding-pair surveys conducted in northern Manitoba by the United States Fish and Wildlife Service (USF&WS). Analysis of this data for the periods 1964 - 1975 and 1977 - 1988 showed a small increase (approximately 2.6%) in diving ducks in the latter period. However, large year-to-year fluctuations occurred during these periods; thus, the means on which these changes are based would vary somewhat as individual year counts were added or subtracted. The apparent reduction in the diving duck use of the Outlet Lakes area does not appear to be a reflection of a long-term decline in regional populations, as represented by the USF&WS data, since no such trends were evident in this data.

The greatest apparent reduction in diving duck use occurred in Playgreen Lake. It is postulated that changes in the quality of the Playgreen Lake habitat may have been sufficient to reduce the attractiveness of Playgreen Lake to diving ducks in the fall. Many, if not most, of the preferred duck hunting areas traditionally used by Norway House Band hunters are located in the south basin of Playgreen Lake. The apparent reduction in waterfowl availability, most especially diving ducks, has limited opportunities for Norway House Band members to view and hunt waterfowl.

Resource Harvesting

A FEMP examination of the existing data on resource use by the NFC communities (primarily fishing data) indicated a number of major socioeconomic effects such as substantial declines in per capita subsistence fisheries harvests at Cross Lake and Split Lake (for which pre- and post-project data exist), a sharp decline in commercial fish production at Cross Lake, partial contamination by mercury at Nelson House, and increased unit costs of production at Norway House and, possibly, Split Lake. Existing data do not reveal the full suspected range of adverse effects; for example, production levels may be maintained as a result of intensified effort.

The five NFC communities and South Indian Lake are mixed, subsistence-based economies, dependent upon the active use of the local resources, a pattern that has evolved from historic use and occupancy of the region. Physical and biological resource bases (the focus of the FEMP studies) provide the socioeconomic foundation for these communities; changes to the resource bases can trigger a number of interrelated harvesting and subsequent socioeconomic changes.

The first record of commercial fishing in the NFA area is for Sipiwesk Lake in 1937; the Southern Indian Lake commercial fishery, the largest in the FEMP study area, began in 1942. Commercial fishing is not only important as a major source of cash, but it provides capital items, such as boats and motors, necessary for travel, recreational activities and perhaps most importantly for domestic harvesting. In addition to Southern Indian Lake and its

58 associated inland lakes fisheries, 78 lakes were commercially fished in the FEMP study area.

Trapping is the other major commercial resource harvesting activity for which an extensive data base exists in the FEMP study area. Records of the trapping harvests begin shortly after the introduction of the registered trapline system in the mid-1940s. There are about 226 traplines, totalling 102,650 km^2, in the 4 registered trapline zones of the NFC communities; up to 15 species of fur bearers are harvested . The South Indian Lake registered trapline section, the second largest in Manitoba with an area exceeding 35,000 km^2, contains an additional 50 traplines. As documented in a recent study (Hrenchuk 1991), this area is extensively and intensively used by the residents of South Indian Lake.

Fishing and trapping data bases for the five NFC communities were examined to assess their potential to provide indicator data on the socioeconomic effects of the LWCN project. Some preliminary observations on resource harvesting impacts were also made to the extent that existing data permitted; observations were limited almost exclusively to fishing because the task of organizing the fur harvest data for this purpose was beyond the scope of this study. Although South Indian Lake was excluded from this FEMP study, partly because it was the subject of other socioeconomic studies, the conclusions from the FEMP resources harvesting study, in general, apply equally well to this community.

It was concluded that the commercial fishing and trapping data bases could provide reasonably reliable indications of harvest level that could be identified (for the most part) at satisfactory levels of geographic detail; moreover, these data have substantial historical depth. However, the fisheries data provide only limited information on harvesting effort, and the trapping data provide none at all. There are no other continuous records that can be used as impact indicators for resource harvesting. Estimates of subsistence harvesting are discontinuous in time and space, and idiosyncratic in method. Also, there are insufficient data on other resource harvesting activities such as hunting of waterfowl and large and small game, as well as the gathering of berries and medicinal plants, to permit any assessment of the LWCN project on them.

In addition to the limited existing data on resource harvesting, there is a problem of interpretation. For example, effort and return in fishing have responded to market forces, such as fish prices and alternative employment opportunities, and perhaps also to changes in the community and reserve economies, in addition to project effects. Furthermore, focusing exclusively on economic losses likely undervalues the importance of fishing to the affected communities. Therefore it is important that fishing and all resource harvesting activities not be assessed in isolation and out of context. Unfortunately, there has been no comprehensive social impact assessment, which would provide such a context, conducted in any of the six native communities within the FEMP study area; until this occurs, it will not be possible to fully understand the implications, including those for impact assessment of the biophysical changes on the FEMP native communities.

Future Studies

The hydrologic regime of the Churchill and Nelson rivers and their associated ecosystems is a dynamic system; natural and man-made factors interact to produce a constantly evolving environment. The FEMP investigated a few, important changes in this environment in some depth. Broader understanding of these changes will require an integration of the results of all research and monitoring programs in this area and new, innovative approaches for future studies.

As noted in chapters 1 and 2 of Volume 1 of this report, the richness of northern Manitoba's natural resources has provided a strong base for the development of forestry, mining, and hydroelectricity. The importance of the area's resources has always extended beyond its geographic boundaries - from its historic role as the gateway to western Canada, through its navigable waters and abundant supply of beaver, to its promise of continued provincial economic strength, through the potential power sales and expected job creation resulting from future hydroelectric projects. These developments have altered terrestrial and aquatic environments, beyond the range of natural variability; possible future climatic change may further exacerbate these alterations.

As discussed in chapters 3 and 4 of Volume 1, the objective of FEMP was to conduct an environmental research and monitoring program to examine changes since the Lake Winnipeg, Churchill, Nelson (LWCN)

Rivers Hydroelectric Project, and to increase our understanding of the significant factors that could affect future ecological conditions in the FEMP study area. This area focused on the immediate vicinity of the six native communities located in the LWCN project area. Of the many factors considered in the selection of FEMP projects, one of the most important was scientific methodology. Although some FEMP projects were new initiatives, many were a continuation of research and monitoring activities previously initiated in the FEMP study area. This resulted in the creation of a number of long-term data bases that were invaluable in assessing environmental changes.

It is apparent from the results of those FEMP projects with long-term data bases that short-term conditions were not necessarily indicative of long-term conditions (e.g. the status of the pike population in Wupaw Bay, Southern Indian Lake; benthic populations along the Churchill River Diversion; water quality conditions at Thompson). Furthermore, data bases that are long-term and fairly extensive, such as the water quality data at Thompson, can be segmented into discrete periods that can be used to develop an understanding of impacts which are specific to a particular period of time. (e.g. a doubling in total phosphorus concentration between the pre- and immediate post-development periods).

FEMP also clearly demonstrated the importance of research, and not just monitoring, activities in assessing environmental change. For example, it was a combination of long-term data and research that ascertained that the changes in the mayfly population in Southern Indian Lake following impoundment and diversion were mainly due to the influence of natural factors. Similarly, research has been the basic component of an ongoing mercury program along the Churchill River Diversion route that has attracted worldwide attention.

To a considerable degree, an attempt was made to incorporate the results of concurrent, non-FEMP environmental programs in the FEMP study area into the analysis of the FEMP data and report preparation: integration of all results, however, must await full completion of all individual project reports, both federally and provincially. However, even with such integration, a number of important environmental changes, affecting either the FEMP study area or beyond it, will not have been addressed. The downstream impact on Hudson Bay of the LWCN project is one outstanding example. The cumulative impacts of all changes in the FEMP study area since the LWCN project (e.g. 1989 forest fires) is another example. Addressing this full range of environmental impacts will require the development and application of innovative approaches, which ideally should result in an integrated long-term, multi-party research and monitoring program.

The ultimate test of FEMP will be our ability to accurately predict future conditions in the FEMP study area, based on the improved understanding of post-development environmental conditions that FEMP has generated.

FEMP results have improved our understanding of the pre- and post-development environmental conditions in the FEMP study area. This understanding will be invaluable in the continuing determination of a just and fair compensation settlement to the people adversely affected by the LWCN project and in the assessment of potential, effective mitigation measures. FEMP's results may prove to be equally valuable in predicting future conditions.

The results of the FEMP research and monitoring activities have lead to an improved understanding of post-development environmental conditions in a major northern Canadian river system. This understanding forms the basis for projecting future conditions, e.g. the estimated time it will take for mercury levels to return to normal, and for shorelines along certain reaches of the Churchill River Diversion to stabilize. In short, this understanding has been used to make predictions.

These predictions must now be tested. If proven accurate, the predictions will be a verification that our perceived understanding of the post-development conditions was correct. Even if the predictions prove to be only partly accurate, they will have identified issues requiring further attention.

These predictions must first be tested in the FEMP study area, where the knowledge on which the predictions were based was gathered. If the results of the prediction testing are promising here, further testing of the predictions, can be expected in other northern regions experiencing similar environmental conditions. In this manner, FEMP may contribute to the growing scientific understanding of aquatic ecosystems in boreal regions.

The significance and implications of the FEMP results will depend upon the point-of-view and time horizon chosen in the interpretation of these results.

FEMP results have been presented in an accurate, clear, and objective manner, with only limited interpretation of their significance and implications. This format was necessary because interpretation of these results depends upon the reader's perspective. For example, erosion to-date along the riverine reaches of the CRD has not been nearly as serious as was predicted in pre-diversion studies; nor does it appear that the erosion has been serious enough to substantially affect flows and water levels. Yet, as shown by a FEMP pilot project, measurable differences in shorelines have occurred over time causing varying degrees of shoreline erosion and sediment generation. This erosion, along with inundation, has resulted in debris-clogged shorelines, which have impeded access to and from the shorelines and travel along the waterways. Thus it would depend on the point-of-view chosen (e.g. viewing the river as a source of hydro generation or as a transportation corridor) whether the changes in the shorelines are perceived to be significant.

Another example is the mercury issue. There is no evidence that elevated mercury levels found in the fish along the CRD, the highest in the FEMP study area, have been sufficiently high to cause problems in the fish populations (e.g. death, reproductive failure, etc.). However, the elevated mercury levels in fish have been the source of considerable concern to the native residents of the FEMP study area, particularly with respect to their health. This concern, which clearly emerged as an issue in the community interviews conducted for the FEMP videotape, has been strong enough to cause distrust of what has been a traditionally important staple in their diet, even though most mercury levels in the adult population are within the normal level.

The mercury issue is also an example of the importance of the selected time horizon in assessing the implications of the FEMP results. The estimated return to pre-impoundment mercury levels of 80 years means that mercury will still be an issue for the next few generations.

RECOMMENDATIONS

Water Quantity and Quality

It is recommended that documentation of the FEMP hydrologic investigations be widely circulated.

Results from the FEMP hydrologic investigation became available too late to allow full documentation of the methodology in the FEMP Final Report. It is imperative that this documentation be widely circulated to ensure that the basis for the derivation of the hydrologic results is well understood, since an understanding of the changes in the hydrologic regime is essential to an understanding of the changes in the aquatic ecosystem.

For example, research has identified the importance of the amount of flooded organic terrestrial material to mercury methylation, the process that is responsible for elevated mercury levels in fish in the FEMP study area. Thus, an increase in lake surface area due primarily to the flooding of terrestrial material, as opposed to the incorporation of existing water bodies, would be expected to result in elevated mercury levels in fish. In Notigi Reservoir, 551 km^2 of the 580 km^2 increase in surface area was due to the flooding of terrestrial material; mercury levels in this reservoir are among the highest in the FEMP study area.

The FEMP water quality study identified three areas of investigation that should be pursued to improve our understanding of current water quality conditions: 1) an investigation of the potential for inferring water quality changes at the FEMP water quality sites in the Outlet Lakes area by using surrogate pre-development data; 2) monitoring water quality in the Split Lake area during periods of higher Nelson River flows to differentiate water quality changes due to low flows, such as those that occurred during the FEMP study, from changes due to the LWCN project; and 3) an evaluation of the inferred sediment deposition in Split Lake near the mouth of the Burntwood River on local water quality, e.g. deposition and future potential mobilization of associated heavy metals.

The FEMP water quality study was a comprehensive investigation in which all relevant historical water quality data and data on current water quality conditions were examined to assess water quality changes. In general, additional data collection in the future will not enable any further understanding of those water quality changes which have already occurred in the FEMP study area. There are, however, three potential areas of investigation that may provide additional insight on some localized changes.

The impact of the LWCN project on the water quality at the FEMP water quality sites in the Outlet Lakes area could not be determined due to the lack of sufficient predevelopment data. This deficiency can not be alleviated by further sampling; however, pre-development water conditions at these sites may be inferred from existing pre-development data at upstream sites. An investigation would be necessary, however, to determine if the predevelopment data from these surrogate sites could be used for this purpose, e.g. information on natural erosion sites and locations of man-made facilities would have to be assessed to determine if there were any natural differences in water quality between the FEMP sites and their respective surrogates.

The low Nelson River flows during the FEMP study period made it difficult to determine if the apparent changes in water quality at the inlet to Split Lake, and in the water quality - water discharge relationships at the inlet and outlet to Split Lake, were due to the LWCN project or to low flow conditions. There is a need for continued monitoring over a wider range of flows to discriminate natural from project-induced changes, if any have occurred. The monitoring program should be consistent with the design of the FEMP study, with a similar sampling frequency, although the number of variables measured could be reduced without any significant reduction in information. A 2-year program would be the minimum required to enable statistical analysis.

The Churchill River diversion has undoubtedly had a substantial impact on sediment deposition rates in Split Lake near the mouth of the Burntwood River, and possibly has affected sediment chemistry in this region. Documentation of the extent and magnitude of sediment-related impacts in this part of the lake is required. Variables monitored should include the rate and location of sediment deposition and the chemical composition of the sediments with emphasis on metals and on factors regulating metal mobilization.

The FEMP water quality data has provided a substantial baseline for the assessment of the impacts of future projects; however, this data base should be *augmented by the continued monitoring of water quality at Thompson, to assess the long-term changes on the Churchill River Diversion, and the collection of water quality data at additional stations where future hydro dams will be built, to examine specific or localized impacts. Further study should also be considered of those issues that offer the potential for improved understanding of future impacts, e.g. the predictive ability of certain water quality - water discharge relationships.*

Although the major changes in water quality appear to have occurred along the Churchill River Diversion (CRD), the length of time required for the system to reach a new equilibrium is unknown. Thus there is strong justification for continued monitoring of water quality at a minimum of one site. Thompson is an excellent site for this purpose because: 1) it is located below the major reservoirs on the CRD; 2) it has the most complete data record of any site in the FEMP study area; and 3) it is readily accessible. Annual monitoring is probably unnecessary, with a 5-year interval between monitoring periods providing adequate coverage. Each monitoring period should be a 2-year study which repeats the FEMP study sampling and analytical methods exactly.

Additional water quality stations may be necessary at, or near, the sites of future hydro dams to examine specific or localized impacts. It would be premature to identify additional station locations at this time without more information on the planned dams. As the results of the FEMP study clearly indicated, there is really no substitute for solid pre-development data. Thus, it is recommended that three years of data be collected prior to construction, with a sampling frequency comparable to that of the FEMP study, to establish pre-development baseline conditions at any new sampling station.

Any future field activities should include an examination of the predictive ability of the water quality - water discharge relationships identified in the FEMP water quality study. Such studies would involve the measurement of discharge-correlated variables over a range of discharges, and the comparison of predicted and observed values.

Another issue that warrants further consideration is the need to develop an estimate of the expected duration of elevated turbidity levels along the CRD. The eroding banks and shoreline should gradually stabilize over time, but the lack of a significant decline in turbidity since diversion indicates this may be a very slow process. An estimate of duration is necessary both for complete documentation of the impact of the CRD on the sediment regime in the Burntwood River, as well as for an assessment of the impact of future modifications to the operation regime.

Sediment and Morphology

A classification system to characterize shoreline types in the FEMP study area should be developed and implemented; this system should enable quantification of the amount of each shoreline type and of the changes in these amounts. Rates of shoreline erosion and changes in these rates over time must be an integral part of this classification scheme.

There have been widespread changes in the land-water interface throughout the FEMP study area and in some areas, such as along the CRD, these changes have been dramatic. Yet, to date, there has been only limited documentation of the magnitude and the extent of these changes. Continuing, and perhaps increased, bank instability from past hydro developments, along with expected changes from future planned developments, will further alter the shorelines of the lakes and rivers in the FEMP study area.

A vital first step in improving our understanding of the past and expected future changes in the shorelines of the FEMP study area is to develop and implement a classification system to map the distribution of shoreline characteristics. A few examples of such characteristics include standing inundated debris or vegetation, actively eroding areas of shoreline, bed rock controlled shorelines, treed muskeg shorelines, treed muskeg shorelines with permafrost, etc. The classification system could be developed by building on the classification scheme used in the LWCN study and incorporating appropriate modifications derived from relevant models elsewhere, such as the classification system used in the La Grande project in Quebec.

It is strongly recommended that representatives from all four parties to the NFA participate in the prioritization of shoreline areas for classification and in the development of the classification criteria. The high cost of even a limited morphological field program in the FEMP study area necessitates the prioritization of sites. Technical criteria, such as the availability of large-scale current and historical air photos (e.g. 1:20,000) and the physical characteristics of the site (e.g. the presence of permafrost) must be considered in the selection of sites for field studies. However, undoubtedly, the most important criterion will be the representativeness of the chosen sites as indicators of the changes of greatest interest. Care must also be taken to ensure that the classification scheme accurately portrays all of the shoreline features of most concern to the area's users.

Field investigations are necessary to provide clarifying additional information in those instances where a definitive classification of shoreline types is not possible from an air photo interpretation, e.g. in distinguishing between near shore areas of floating vegetation and areas of shallow water with emergent vegetation. The determination of the rates of shoreline recession also require field investigations. For example, on-site verification of bank heights and of the ice content of eroded material would enable more accurate calculation of the volume of material eroded. Similarly, resurveying established cross sections would identify any areas of bed degradation which may be undermining bank stability. (It should also be noted here that in addition to field investigations, a knowledge of stage-discharge relationships would be required to accurately distinguish between shoreline changes due to inundation versus erosion.)

Results of this shoreline characterization program, including measurements of bank stability, along with the application of erosion models, such as the one developed for Southern Indian Lake, could provide insight on the expected alteration of active shorelines and thus of the duration of related changes such as increased rates of sediment production and the availability of organic material to stimulate methyl mercury production. In addition, it may also lead to the identification of localized sites where remedial measures, such as bank protection, may prove viable.

A field investigation should be conducted to document major sediment sinks along the CRD and most especially at Split Lake, where evidence suggests that active delta formation is occurring at the inlet of the Burntwood River to Split Lake. This program would complement the identification of sediment sources which will be one result of the shoreline classification and monitoring program previously recommended.

Within the FEMP study area, sediment deposition has been investigated only in Southern Indian Lake and to a much lesser extent in Playgreen Lake. The importance of sediment deposition to fisheries and water quality and the knowledge that the sediment load carried by the CRD has increased argues for the need to have a better understanding of the locations and rates of sediment deposition, at least for the major sediment sinks. Suggested study locations include Footprint Lake, Threepoint Lake, Rat Lake, and especially Split Lake.

Sediment deposition in Split Lake is of particular concern because the incoming sediment load is largest there, the lake is large enough to ensure significant deposition, and there is an established fishery used by the residents of Split Lake and York Landing. Therefore, an intensive sediment deposition study is recommended for this location, including repetitive topographic and bathymetric surveys off the mouth of the Burntwood River, and a repetitive program of lake sediment coring to determine the rate, spatial extent and grain size of deposited sediment. To provide an independent assessment of sedimentation rates, a number of sedimentation pans should be set out in representative locations.

Mercury

Investigations should be continued into the following mercury issues examined under FEMP: 1) additional studies into the microbial demethylation process, the more poorly understood of the two microbial processes regulating the net production of methyl mercury; 2) the potential contribution of downstream transport of methyl mercury to elevated mercury levels in fish; and 3) the continued monitoring of mercury levels in fish from lakes that are important domestic fisheries to the six native communities in the FEMP study area.

Studies to date have suggested that microbial demethylation rates like microbial methylation rates are regulated by organic matter availability and total microbial activity; however, these observations need to be confirmed. There is also a need to determine why demethylation appears to be independent of sediment oxygen conditions, whereas methylation increases under anoxic conditions. Such investigations may result in the identification of possible measures for stimulating demethylation and thus potential mitigatory action. Currently, fish management activities, such as the selective harvesting of fish with lower mercury levels, are the only viable mercury mitigatory measures. Fish management activities, however, may have potential negative impacts (e.g. future spawning stocks) that could have socioeconomic effects on the resource users in the FEMP study area.

Investigations should be conducted into the range and mechanism of the downstream transport of mercury in the FEMP study area. In particular, the relative importance of water, the movement of mercury-contaminated fish, and the movement of mercury-contaminated food for fish (e.g. zooplankton, invertebrates, and prey fish) as the pathway(s) for the downstream transport of methyl mercury is unknown. A recommended geographic focus for the downstream transport study is Split Lake where mercury levels in pike and walleye appear to be uncharacteristically high for a non-flooded lake on the Nelson and Burntwood rivers. This study could include: 1) measurements of methyl mercury in water in the major inflows to Split Lake; 2) a tagging program to document fish movements from Sipiwesk Lake and the Kelsey forebay; and 3) an examination of the potential effect of fish killed in the Kelsey turbines or of a site of elevated net mercury methylation within Split Lake.

Commercially harvested fish are routinely monitored by the Department of Fisheries and Oceans for mercury concentrations; however, there is no on-going program to monitor mercury levels in fish from lakes that are important domestic fisheries in the FEMP study area. It is recommended that regular, periodic monitoring of mercury levels in fish be conducted in these lakes.

All future hydro projects in northern Manitoba, and most especially those along the CRD route, should include mercury research and monitoring activities, as well as possible preventative measures, which apply and build on the results of the FEMP mercury program.

Environmental impact assessments of proposed hydro projects, such as Wuskwatim Dam, should include mercury studies undertaken before, during, and after the construction of the planned hydro dam and reservoir creation. These studies should include such activities as the measurement of methyl mercury in water in the reservoir and immediately upstream and downstream, the monitoring of mercury levels in fish in the reservoir and immediately downstream, and the measurement of methylation (M) and demethylation (D) rates in the reservoir. "Pre-development" measurements (i.e. measurements taken before the construction of Wuskwatim Dam) of M and D rates, which currently do not exist for any location in northern Manitoba, along with the M and D rates for the construction and immediate post-operation period, would provide valuable additional data for the mercury duration model. (It is important to note, that Wuskwatim Lake has already been affected by the increased flows along the Churchill River Diversion and hence can not be considered a "pristine" lake.)

Shoreline characterization of future reservoirs, such as Wuskwatim, as recommended previously in this chapter, would provide information on the terrestrial organic materials (e.g. plant species, soil types) to be flooded. This information could be used in a pilot project of controlled burning of organic material to evaluate the effectiveness of this technique as a preventive measure and to assess potential adverse environmental side-effects. In addition, sediment deposition studies in the reservoir could be conducted to assess the role of sediment deposition in the net production of methyl mercury.

The newly-constructed weir at the outlet of Cross Lake has caused concern among the residents of the Cross Lake community because of its potential impact on mercury levels in fish. The weir is intended to raise the low water level without affecting the high water level; no back flooding of bog or forest terrain is expected. Thus, the weir is not expected to cause increased fish mercury levels. However, this assessment should be confirmed by a fish mercury monitoring program for at least two years after the weir is constructed.

Fisheries and Aquatic Life

A limited research and monitoring program to complete and/or follow-up on the results of fisheries and benthic studies in the FEMP study area is recommended. These activities include periodic sampling of biological indicators of the Southern Indian Lake fishery, completion of the whitefish morphological study in the Playgreen Lake area, and completion of the study on the fish migration through 2-Mile Channel.

The results of the FEMP studies of the Southern Indian Lake whitefish fishery suggest that it may be showing marginal improvement or stabilizing at levels lower than pre-impoundment values. Periodic sampling should be conducted to collect data on key indicators such as catch per unit effort, grade, and condition in order to assess the long-term status of the Southern Indian Lake whitefish. Consideration should also be given to a concurrent program of data collection to assess the long-term status of the pike population in Wupaw Bay, Southern Indian Lake.

Two related FEMP investigations were undertaken of whitefish populations and their movements in the Playgreen Lake - 2-Mile Channel - Lake Winnipeg area. Results of the genetic analysis component of this investigation were presented earlier in this report; however results from the morphological analysis, which is yet to be conducted, may allow for the identification of additional stocks not ascertained by genetic analysis. This may change the tentative conclusions reported to date. Additionally, a report should be prepared on the results of the study of fish migrations through 2-Mile Channel. This is dependant on the correction of problems with computer software for the analysis of the echosounder digitized data.

It is recommended that a pilot project be undertaken to test various mechanisms to transfer whitefish over the Missi Falls Control Structure into Southern Indian Lake (SIL) in those years when discharge over Missi Falls is high. Local participation and a scientific assessment of the effectiveness of each mechanism must be integral components of the pilot project.

In 1986, the mean discharge at Missi Falls from June to August approximated that of pre-impoundment conditions; large numbers of whitefish were observed below the Missi Falls Control Structure, most of which appeared to have originated from SIL. In contrast, in 1987, a year of lower flows than in 1986, lower numbers of whitefish were observed, most of which appeared to have originated from the lower Churchill River lakes downstream of Missi Falls. It is recommended that a pilot project be undertaken, in years of high discharge over Missi Falls, to evaluate mechanisms to transfer whitefish back into SIL.

An evaluation of the mechanisms tested in the pilot project, such as a seining program or fish ladder, should include: 1) documented numbers of fish successfully transferred; 2) an assessment of the critical factors affecting success; 3) cost; and 4) the impact on the SIL whitefish fishery. The pilot project should be implemented and evaluated with the support of the Southern Indian Lake fishermen, since their long-term involvement will be an important factor in selecting any mitigation measure based on the results of this pilot project.

There is some suggestion that whitefish may also be leaving Southern Indian Lake through South Bay. Consideration should also be given to a research program to investigate this possibility, with the assistance of the fishermen from South Indian Lake and possibly Nelson House.

Waterfowl

It is recommended that future surveys of ducks and geese conducted in the FEMP study area be of sufficient intensity and duration to enable assessment of temporal and spatial trends, with some degree of confidence.

No additional amount of data collection now will enable any further assessment of changes which have already occurred in the numbers of ducks and geese in the FEMP study area since the LWCN project. The FEMP investigation utilized all existing historical and spatial data to assess waterfowl trends to-date. Additional data collection now, however, could provide a more comprehensive understanding of the current usage of the FEMP study area by waterfowl and provide baseline data for an assessment of future changes.

Potential specific locations for future surveys include the sites of proposed future dams and areas of particular importance to the domestic harvesting of waterfowl by the residents of the six native communities in the FEMP study area. Ground studies, as well as aerial surveys, should be considered.

The work should be carried out with the cooperation of the native communities in the planning and implementation of these studies. Input from these communities is required to: 1) identify their waterfowl harvesting areas; 2) provide assistance in the field studies; 3) help identify critical sampling times; and 4) provide data on domestic waterfowl consumption.

Resource Harvesting

It is recommended that the appropriate parties to the NFA conduct a social impact assessment (SIA) of the LWCN project on the six native communities in the FEMP study area. An SIA involves the selection and justification of a basic paradigm of social change, the identification of appropriate variables and indicators, and a workable system for monitoring these indicators on a continuing basis.

Post-construction socioeconomic assessments in the project - affected area have been oriented almost exclusively to the accounting and evaluation of damages for the purposes of compensation or mitigation, rather than to the understanding of the processes or the significance of social change as such. Damage accounting, however, has little analytic or predictive value, and it does not provide an adequate basis for systematic monitoring of project effects, without which predictions cannot be verified.

A social impact assessment of the project effects on the six native communities located within the FEMP study requires a generic model of their economy that specifies its characteristics and properties. One distinctive characteristic of these communities is the place of resource harvesting as a central and integrative activity, and of subsistence as a socioeconomic system. Subsistence activity does not constitute a separate and distinct economy in these communities but is combined at the individual, household and community levels with wage labour and transfer payments. Both subsistence activities and subsistence outputs are essential for the maintenance of the social system. A SIA model for these communities must be based on the central importance of subsistence activities to them.

A review of the existing data identified the type of additional data that would be required to conduct a SIA. These data include the level of harvesting effort, the amount of domestic consumption, and a better understanding of the social and economic organization of resource harvesting activities (e.g. native land tenure). Meeting this entire range of data needs would require a combination of survey, extended interview, participant observation, and archival research. Clearly, satisfying these data needs requires that the SIA must be community based, not only in implementation and execution but also in design and control.

Greater community involvement has been recommended elsewhere in this chapter with respect to environmental monitoring programs. Indeed, continuation of one FEMP-initiated program, an assessment of the bacterial quality of the communities' drinking and recreational water, has been assumed by one NFC community, Split Lake, with the financial and technical support of the International Development Research Council. Further community involvement in environmental monitoring programs is clearly desirable, but community involvement is absolutely essential in order to understand the socioeconomic consequences of environmental changes.

Future Studies

It is recommended that future Canadian river basin studies, and more generally environmental studies, be conducted using an ecosystem approach. This will require the design and implementation of integrated programs that encompass inter-disciplinary, inter-jurisdictional research and monitoring activities.

Canada's large share of the world's fresh water and her status as a world leader in hydroelectric projects behooves us to understand the consequences of alterating aquatic ecosystems. There is a growing recognition within Canada of the importance of sound environmental management, which focuses on the anticipation and prevention of environmental damage. Opinion polls of the last few years have consistently shown the Canadian public's strong commitment to environmental action, even in the face of tough economic times. In order for this environmental action to be effective it must be the result of an informed decision-making process.

An attempt to provide a rational framework for a national environmental policy was the motivation for the recently released Green Plan. One of the stated goals in Canada's Green Plan is "to strengthen the nation's environmental science and technology with a special emphasis on understanding regional ecosystems." The need for federal leadership in water science has been an increasing concern as echoed across the country in a series of regional workshops on water science held by the Science Council of Canada in 1987. In particular it was noted that the needed wide-ranging, long-term ecological studies are absent and that "big" issues such as ecotoxicology, the impact of river diversions, and studies of the marine-freshwater interface have been neglected.

Although the impetus for FEMP was the Northern Flood Agreement, it is clear that FEMP was a definite step along the path prescribed by the Science Council of Canada and by the Green Plan. It was a multi-year, multi-disciplinary research and monitoring program that examined post-development conditions of an area affected by a major river diversion. Above all, it was a scientific investigation that increased our basic knowledge of the physical, chemical, and biological processes related to ecosystem disturbance and recovery.

Progress in attaining Canada's environmental goals will require an increased usage of the ecosystem approach in investigating water issues and a continued improvement in the methodology for conducting ecosystem studies. In this regard, the lessons of FEMP can serve as a guideline with respect to the needed scientific and administrative framework.

The results of FEMP should be applied to the design and implementation of environmental impact assessment studies at Wuskwatim.

Current Manitoba Hydro plans are to build the next dam at Conawapa on the lower Nelson River; the relevant FEMP results should be incorporated into the planned environmental impact assessment (EIA) for this dam. However, it would be the construction of a dam at Wuskwatim Lake on the Churchill River Diversion (CRD) that offers the first opportunity to fully incorporate FEMP results into an EIA in this region.

Throughout this chapter, studies have been recommended that would test FEMP predictions, expand the extent of and our confidence in the existing data bases, and address identified needs. Collectively, these recommended studies would further our understanding of this changed, and still changing, ecosystem. Most of these recommendations could be implemented as part of the Wuskwatim EIA. Past hydro development projects have already had an effect on Wuskwatim Lake (e.g. changed surface area, changed benthic invertebrate populations, etc.) that must be considered in the collection of EIA "pre-development" data. However a Wuskwatim EIA could still provide a valuable opportunity for building upon the results of FEMP.

FEMP recommendations on sediment, morphology, and mercury, in particular, offer a wide scope of productive avenues to pursue. Potential sediment and morphology issues include: 1) testing of DFO's Southern Indian Lake erosion model; 2) development of a shoreline classification scheme; 3) continuation of the FEMP airphoto interpretation to generate estimates of erosion; and 4) the initiation of field studies to ground-truth information obtained from remote sensing techniques. Potential mercury issues include: 1) measurement of pre- and post-Wuskwatim Dam methylation and demethylation rates; 2) measurement of mercury concentrations in fish and water; 3) investigation of the possible downstream transport of methyl mercury from Wuskwatim via water and fish; and 4) a pilot project to assess the effectiveness of controlled burning of organic material as a possible preventive measure in the accumulation of methyl mercury by fish. Other potential issues arising from FEMP that could be further investigated include: 1) waterfowl surveys; 2) benthic populations, and 3) measurements of selected water quality variables, such as turbidity, before and after the construction and operation of Wuskwatim Dam.

Other recent or anticipated studies that could be used in a Wuskwatim EIA include: 1) environmental studies in the LWCN impact area conducted by Manitoba Hydro and the Manitoba provincial government; 2) regional environmental studies, such as the planned Boreal Ecosystem - Atmosphere Study (BOREAS), a joint Canada/NASA ecosystem study that will include a study site near Nelson House; and 3) the on-going environmental studies being conducted as part of the James Bay project in northern Quebec. Collectively, these studies, and most especially FEMP, will provide excellent guidance for the design and implementation of a Wuskwatim EIA.

The necessity for a strong administrative framework should be recognized early and incorporated into the design of all future major environmental research and monitoring programs. Early establishment of this framework is vital to the attainment of a program's goals.

Like FEMP, all major environmental research and monitoring programs build on the results of past investigations and lay the foundation for similar investigations in the future; these programs do not, or rather should not, exist in isolation. However, in order to ensure that a program benefits from the results of previous studies, a number of administrative "housekeeping" tasks must be initiated early in the program. These include the retrieval and standardization of existing data and the determination of methods used in past studies. This information is essential if temporal analysis is one of the program's objectives. If multi-disciplinary studies are planned, there will also be a need for common basic information such as current and accurate maps of the study area.

The need for strong administrative support continues throughout the study, especially in the provision of secure and sufficient program funding, and in ensuring enough flexibility to enable reallocation of funds between years and projects as program requirements demand. Other important requirements include the need for program management and for scientific review of all program proposals and project findings; mechanisms for both functions must be in place early. There must also be full documentation and permanent archiving of data if the program is to be useful in the planning of future studies.

Another essential, but unfortunately often undervalued, administrative task is the planning and implementation of a vigorous and effective public information program. In particular, public information activities must be designed to address the specific information needs of the target audience and, to the maximum extent possible, facilitate their active participation in the program.

Even this brief outline of selected key administrative tasks illustrates their critical importance in environmental research and monitoring programs. Yet, frequently, many of these tasks are initiated only relatively late in a program; FEMP was typical in this regard. There are a number of reasons for the late establishment of administrative structures. First, the non-routine nature of these programs takes them outside the normal departmental operational experience. Second, the broad objectives and time frames of such programs places them beyond the mandate and resources of any one department. Third, there are constitutional uncertainties regarding responsibilities in water resource issues. The latter problem can result in a "tragedy of the commons" in that what is in the interest of all parties to have is no one's responsibility to provide.

As noted in the Inquiry on Federal Water Policy (1985) "The respective roles of governments is a sensitive issue in federal-provincial relations and seems to have impeded resolution of some water management problems." Definition of roles is further complicated when the water resource issue involves substantial alteration of the environment by developments because a third role, that of the proponent's, is introduced.

Clearly, the strong administrative framework that is required to support the scientific and social investigation of complex environmental issues can best be provided through cooperative action of all involved parties. This would remove constitutional uncertainties and provide a large common pool of resources and experience. Cooperative action also offers the advantage that, through their participation, all involved parties will have a better appreciation of the program's conclusions and recommendations and will incorporate this knowledge into their decision-making process. The ultimate success of programs like FEMP will be their influence on the decision makers of today and tomorrow.

AUTHOR'S ACKNOWLEDGEMENTS

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Thank you one and all.

L. McKerness

L. McKerness
FEMP Coordinator

GLOSSARY, ACRONYMS AND TECHNICAL UNITS

AFFRA - Acoustic Flow for Remote Areas

Al - Chemical symbol for the element aluminum

ANOXIC - deficiency of oxygen

As - chemical symbol for the element arsenic

BACTERIA - group of single or multi-celled, microscopic organisms, lacking chlorophyll

BATHYMETRY - the measurement of depth of water in water bodies

BENTHIC - pertaining to BENTHOS

BENTHOS - organisms that live on or in the bottom of bodies of water

BIOMASS - the amount of living matter (as in a unit area or volume of habitat)

BLACK ICE (OR COLUMNAR ICE) - translucent ice formed by freezing water. It has a relatively course columnar crystal structure

BOREAL - of, relating to, or located in northern regions

C - chemical symbol for the element carbon

Ca - chemical symbol for the element calcium

Cd - chemical symbol for the element cadmium

CHLOROPHYLL a - A photosynthetic pigment in plants. The concentration is used as a measure of algal biomass

Cl - chemical symbol for the element chlorine

CMMA - Canada-Manitoba Agreement on the Study and Monitoring of Mercury in the Churchill River Diversion

CONDITION FACTOR - relative plumpness of fish, usually calculated as weight of the fish divided by the length of the fish (or length cubed)

CORRELATION - the study of the simultaneous variation of two or more variables. If one variable (e.g. mercury concentration) increases as the other increases (e.g. fish size) and decreases as the other decreases there is said to be a positive correlation.

CPU - catch per unit effort, a measure used to describe fishing success

CRD - Churchill River Diversion

^{137}Cs - a form of the chemical element, cesium

Cu - chemical symbol for the element copper

DABBLING DUCK (OR DABBLER) - a duck which typically feeds by "tipping up" so that its tail shows above the water surface; mallards and teals are dabblers

DEMETHYLATION - a process by which a methyl group (CH_3^-) is removed from a compound. In METHYL MERCURY demethylation, methyl mercury is converted into elemental MERCURY.

DFO - Department of Fisheries and Oceans

DIC - dissolved inorganic carbon

DIVING DUCK (OR DIVER) - a duck which typically feeds by diving below the water surface; scaup and goldeye are divers

DOE - Department of the Environment

DORSAL - relating to or situated near or on the back, especially of an animal or one of its parts

ECOLOGY - a branch of science concerned with the interrelationship of organisms and their environments

EIA - environmental impact assessment

ELECTROPHORESIS - the movement of suspended particles through a fluid or gel under the action of an electromotive force applied to electrodes in contact with the suspension

F - chemical symbol for the element fluorine

Fe - chemical symbol for the element iron

FECAL COLIFORM - the type of coliform present in the large intestine and feces of warm-blooded animals

FEMP - Federal Ecological Monitoring Program

FLUVIAL - of, relating to, or living in a stream or river

FORAGE - food for animals, especially when taken by browsing or grazing

FRAZIL ICE - small thin discs of ice, typically about 1 mm in diameter

GLACIO-LACUSTRINE - of, relating to, or coming from lakes deriving much or all of their water from the meeting of a glacier

GONAD - any of the reproductive glands that produce gametes and include the ovaries and the testes

HALF LIFE - the time required for half of something to undergo a process

Hg - chemical symbol for mercury

HOLISTIC - relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into parts; holistic ECOLOGY views man and the environment as a single system

HYDROLOGY - a science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere

HWC - Health and Welfare Canada

ICE JAM - a forced, stationary accumulation of fragmented ice and SLUSH

ICE PAN - rounded pans of ice formed by the congealing of FRAZIL SLUSH ICE at the surface after exposure to the cold air. The pans are characterized by a thickening crust of solid ice with an underhang of SLUSH

ICE SKIM - a thin layer, coating, or film of ice

INORGANIC - not ORGANIC, not containing carbon or compounds of carbon, with a few exceptions

INVERTEBRATES - of or relating to animals that lack a spinal column

IONS - an atom or group of atoms that carries a positive or negative charge as a result of having lost or gained one or more electrons

K - chemical symbol for the element potassium

KEEL - the portion below the water line

LIMNOCORRALS - large enclosures that isolate a defined water mass from a larger body of water

LITTORAL - of, relating to, or situated or growing on or near a shore

LODGEMENT - the bridging of pan and SLUSH ICE between the edges of shorefast ice to begin development of the freeze-up pack.

LWCN - Lake Winnipeg, Churchill and Nelson Rivers

M/D - the ratio of specific methylation rate to specific demethylation rate. Also called the METHYLATION BALANCE

MERCURIC IONS - a divalent MERCURY atom with a double positive charge

MERCURY - a naturally occurring metallic element

METHYL GROUP - a group that consists of 1 carbon and 3 hydrogen atoms

METHYL MERCURY - an ORGANIC form of mercury containing the methyl group (CH_3^-); methyl mercury has a high affinity for animal tissue and is concentrated up the food chain.

METHYLATION - a process by which a methyl group (CH_3^-)is attached to an atom or molecule. In mercury methylation, MERCURIC IONS are converted to METHYL MERCURY

METHYLATION BALANCE (M/D RATIO) - a measure of the net rate of METHYL MERCURY production by BACTERIA

Mg - chemical symbol for the element magnesium

$mg{\cdot}L^{-1}$ - milligrams (10^{-3} gram) per litre

mm - millimetre (10^{-3} metre)

Mn - chemical symbol for the element manganese

MORPHOLOGY - relating to form and structure

N - chemical symbol for the element nitrogen

Na - chemical symbol for the element sodium

NFA - Northern Flood Agreement

NFC - Northern Flood Committee

NFR - Non-filterable residue. A measure of the concentration of suspended sediments in water. Defined as the mass of material in a volume of water that does not pass through a .45 μm membrane filter.

$ng{\cdot}g^{-1}$ - nanogram (10^{-9}) per gram

NH_3 - chemical symbol for the compound ammonia

Ni - chemical symbol for the element nickel

NO_2-NO_3 - chemical symbol used to identify the compounds nitrite (NO_2) and nitrate (NO_3)

NTU (Nephelometric Turbidity Units) - a measure of water clarity; the higher the NTU value, the more suspended matter present in the water

NUTRIENT - any substance which promotes growth or provides energy for a living organism

ORGANIC - relating to, or derived from, living organisms

P - chemical symbol for the element phosphorus

PAB - Program Advisory Board

PARADIGM - an example or pattern, especially an outstandingly clear or typical example or archetype

^{210}Pb - a form of the chemical element, lead

PHYTOPLANKTON - PLANKTONIC plant life

PLANKTON - the passively floating or weakly swimming animal and plant life of a body of water consisting chiefly of minute plants and animals that have only weak powers of movements

PO_4 - phosphorus occurring as the compound PO_4^{3-}. Considered to represent the concentration of inorganic soluble phosphorus, the form directly available to aquatic plants

ppb - a concentration expressed in parts per billion

ppm - a concentration expressed in parts per million. Equivalent units are $\mu g{\cdot}g^{-1}$ and $mg{\cdot}L^{-1}$

PRESSURE RIDGE - a raised section of buckled or fragmented ice caused by failure of an ice sheet in compression due to thermal expansion or collision between floes

PROFUNDAL - pertaining to the deeper depths of a water body

r^2 - a measure of how well the trend in the data is described by a specific mathematical formula, in most cases, a straight line

REMOTE SENSING - is the science and art of obtaining information about an object, area, or phenomenon, through the analysis of data acquired by a devise that is not in contact with the object, area or phenomenon under investigation

RIPRAP - a foundation or sustaining wall of stones or chunks of concrete thrown together without order

RIVERINE - relating to, formed by, or resembling a river

SEECHI DISC - a 1/4 m diameter disc, divided in alternating black and white quadrants. The depth in the water at which the disc disappears from view is used as a measure of the water's transparency.

SIA - social impact assessment

SIL - Southern Indian Lake

SLUSH - unfrozen saturated snow

SLUSH ICE - loose accumulations of FRAZIL particles, either on the surface of the water or under an ice cover

SNOW ICE - ice formed by the freezing of saturated snow. It has a fine grained structure, and a white appearance due to air inclusions

STANDARDIZED MEAN MERCURY LEVELS - mercury levels in fish that are reported on the basis of a standardized fork length in order to provide a consistent standard of comparison between lakes; the standardized fork lengths were 350 mm for whitefish, 400 mm for walleye, and 550 mm for pike

TDN - total dissolved nitrogen

TDS - total dissolved solids

TOC - total organic carbon

TURBIDITY - a measure of the scattering and absorption of light by particles suspended in water. Note that it can be affected by the size and refractive characteristics of the suspended particles and thus need not be directly correlated with the total amount of suspended material

$\mu g \cdot g^{-1}$ - microgram (10^{-6}) per gram

UNGULATE - any of the group consisting of the hoofed mammals of which most are herbivorous and many are horned

USF&WS - United States Fish and Wildlife Service

Zn - chemical symbol for the element zinc

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Appendix 1

Federal Ecological Monitoring Program Sponsoring Agency, Project Duration and Project Expenditures

Project DOE Sponsored	*Duration*	*Total Expenditures* 1986/87 - 1990/91
Wildlife	1986/87 - 1990/91	$49,588.25
Water Quality	1986/87 - 1990/91	549,150.35
Hydrology	1987/88 - 1989/90	46,127.87
Sediment and Morphology	1986/87 - 1990/91	131,391.62
Mercury	1986/87 - 1990/91	241,369.89
Ice	1988/89	15,000.00
Information Synthesis	1986/87 - 1989/90	99,767.44
Public Information	1990/91	58,474.29
Management	1986/87 - 1990/91	253,839.33
Fisheries (DFO Projects)	1987/88 - 1990/91	36,313.04
Report Preparation	1990/91	55,793.25*
		$1,536,815.33

Project DFO Sponsored		
Physical Environment		
- nutrients and primary production	1986/87 - 1990/91	$148,003.91
- shore erosion and sedementation	1986/87 - 1990/91	56,170.04
Lower Trophic Levels		
- benthic and zoo- plankton studies	1986/87 - 1990/91	68,248.36
Fish Populations and Fisheries		
- SIL fish populations and whitefish stocks	1986/87 - 1990/91	165,681.63
- Playgreen Lake fish studies	1989/90 - 1990/91	32,385.54
Management		
- SIL camp	1986/87 - 1989/90	201,898.87
- contracted biophysical studies	1988/89 - 1990/91	26,016.00
- contracted natural resource harvesting studies	1988/89 - 1990/91	105,278.63
- project administration	1986/87 - 1990/91	90,314.45
- report preparation	1990/91	24,626.40
- report publication costs	1990/91	9,720.00
		$928,343.83

* estimated

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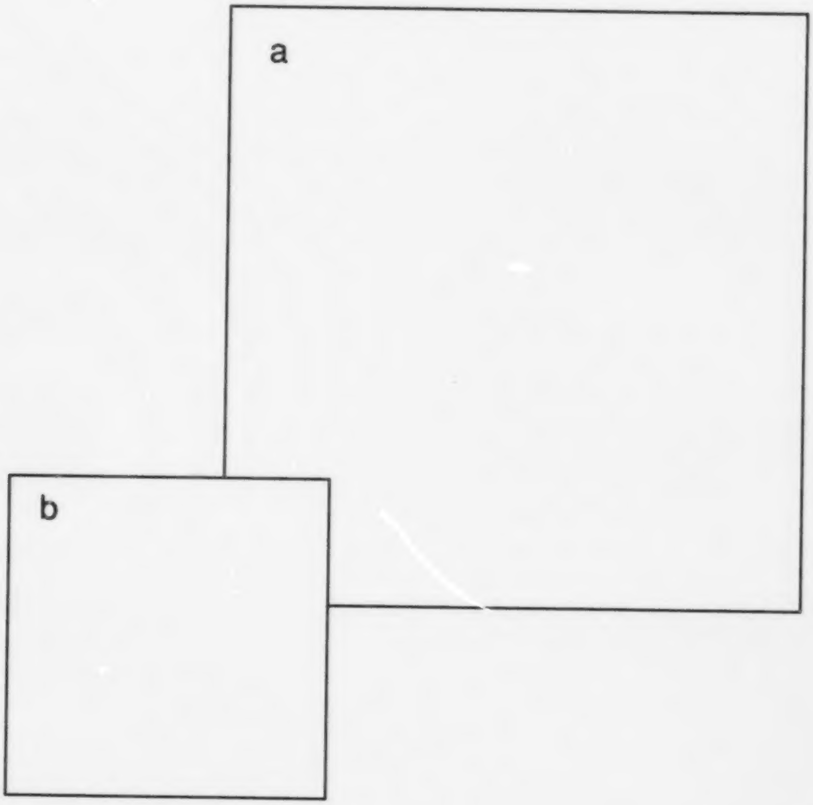
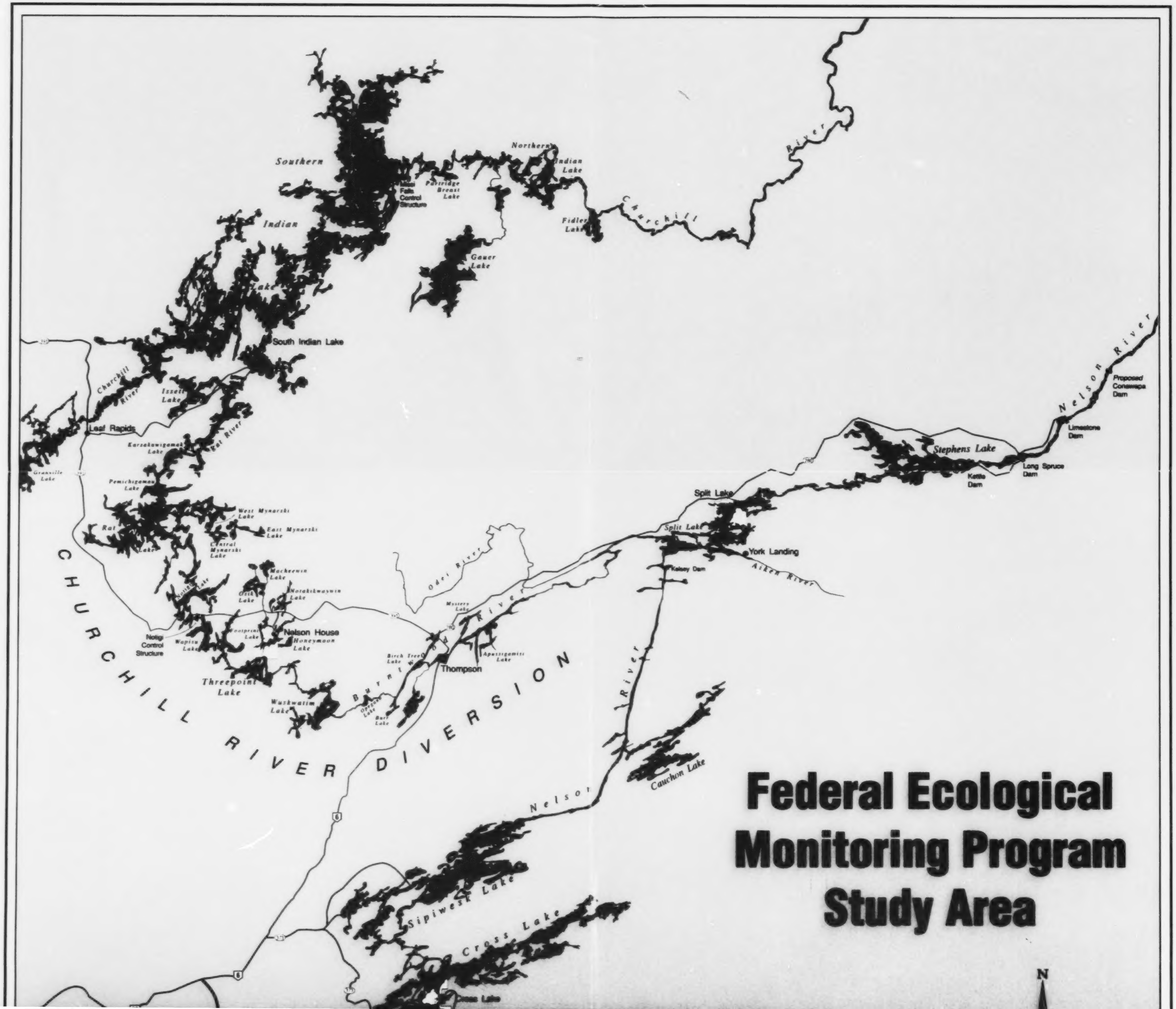


Volume 1

Chapter 1a	Donna Rystaphanuk
b	Festival du Voyageur
Chapter 2a	Impact Video
b	Impact Video
Chapter 3a	Donna Rystaphanuk
b	Canadian Wildlife Service
Chapter 4a	Impact Video
b	Impact Video
Chapter 5a	Impact Video
b	Impact Video

Volume 2

Chapter 1a	Impact Video
b	Impact Video
Chapter 2a	Impact Video
b	Impact Video
Chapter 3a	Impact Video
b	Bill Mavros
Chapter 4a	Impact Video
b	Impact Video
Chapter 5a	Donna Rystaphanuk/Randy Baker
b	Impact Video


Southern
Indian
Lake
Missi Falls Control Structure
Partridge Breast Lake
Northern Indian Lake
Fidler Lake
Churchill River
Gauer Lake
South Indian Lake
Churchill River
Issett Lake
Leaf Rapids
Rat River
Karsakuwigamak Lake
Granville Lake
Pemichigamau Lake
West Mynarski Lake
East Mynarski Lake
Central Mynarski Lake
Rat Lake
Notigi Lake
Macheewin Lake
Osik Lake
Notakikwaywin Lake
Notigi Control Structure
Wapisu Lake
Footprint Lake
Nelson House
Honeymoon Lake
Threepoint Lake
Wuskwatim Lake
Opegano Lake
Burntwood River
Birch Tree Lake
Mystery Lake
Odei River
Apussigamis Lake
Thompson
Bur Lake
Split Lake
Split Lake
York Landing
Aiken River
Kelsey Dam
Nelson River
Stephens Lake
Kettle Dam
Long Spruce Dam
Limestone Dam
Proposed Conawapa Dam
Nelson River
Cauchon Lake
Sipiwesk Lake
Cross Lake
Cross Lake
CHURCHILL RIVER DIVERSION
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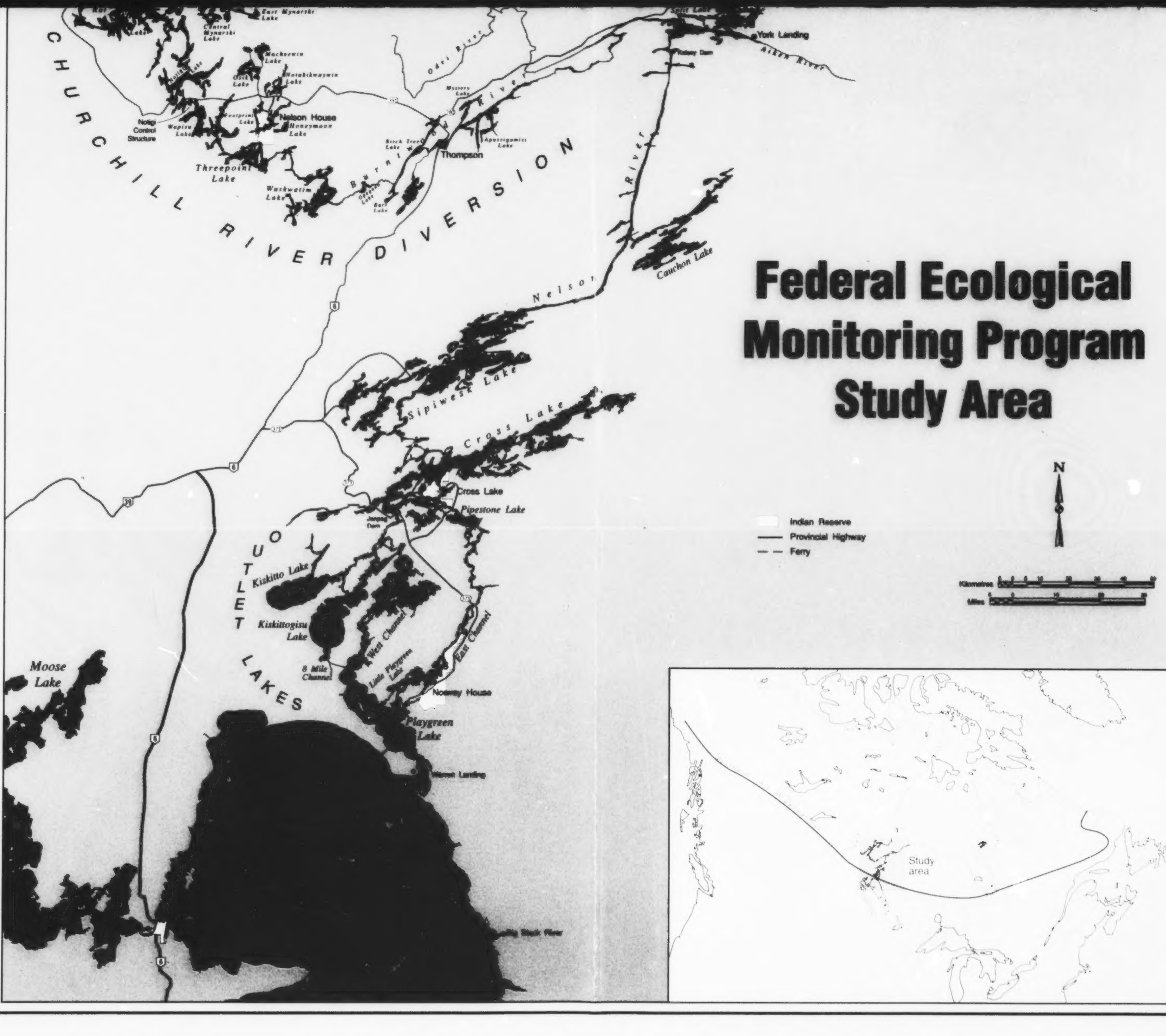
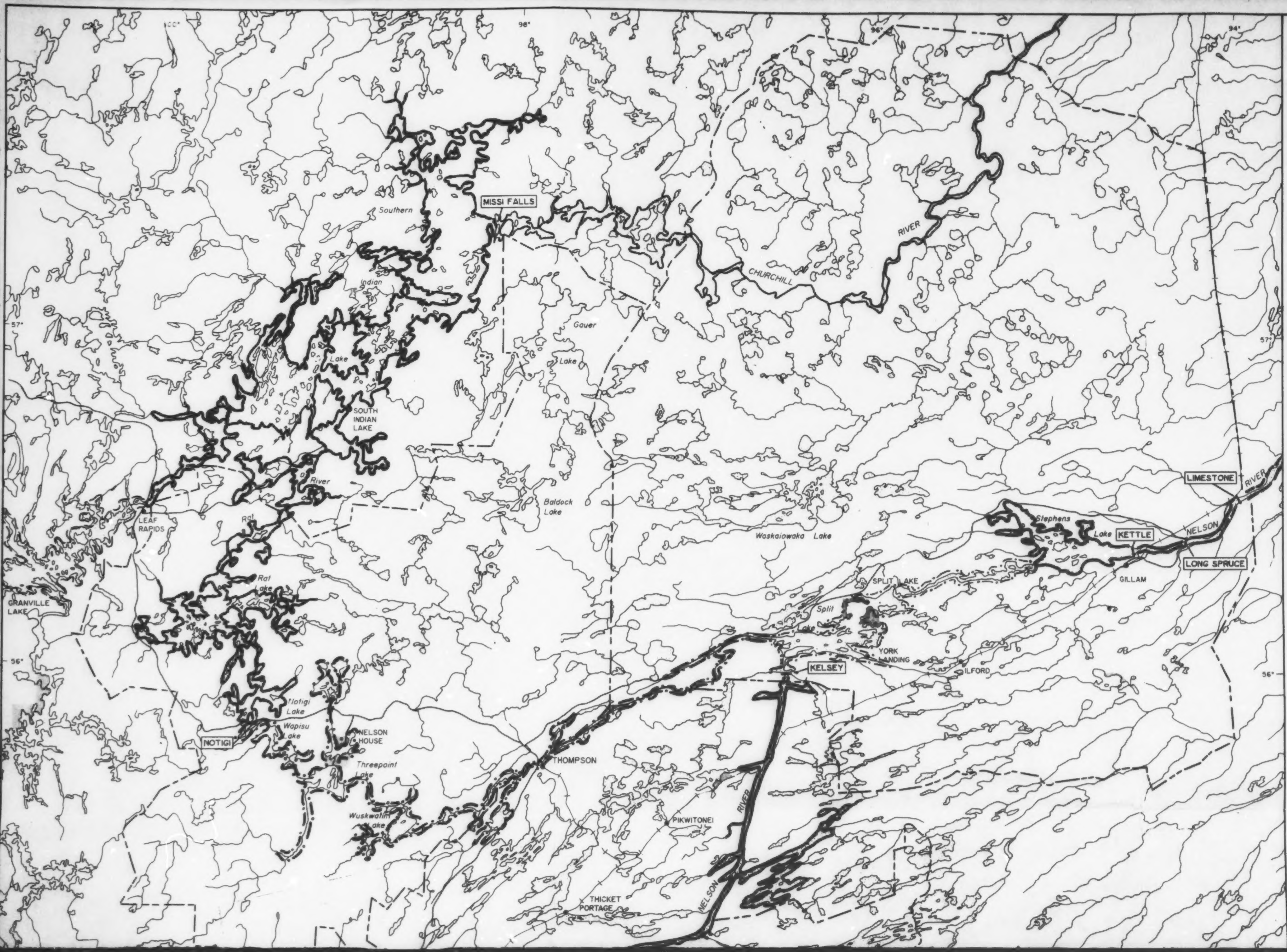
N

Federal Ecological Monitoring Program Study Area



Federal Ecological Monitoring Program Study Area

East Mynarski Lake
Central Mynarski Lake
Notigi Lake
Machewin Lake
Osik Lake
Notakikwaywin Lake
Notigi Control Structure
Wapisu Lake
Footprint Lake
Nelson House
Honeymoon Lake
Threepoint Lake
Wuskwatim Lake
Opegano Lake
Burnt Wood River
Birch Tree Lake
Mystery Lake
Odei River
Thompson
Apussigamisi Lake
Split Lake
York Landing
Aiken River
Kelsey Dam
Nelson River
Cauchon Lake
CHURCHILL RIVER DIVERSION
Sipiwesk Lake
Cross Lake
Cross Lake
Pipestone Lake
Jenpeg Dam
OUTLET LAKES
Kiskitto Lake
Kiskittogisu Lake
8 Mile Channel
West Channel
Little Playgreen Lake
East Channel
Norway House
Playgreen Lake
Warren Landing
Moose Lake
Black River
6
39
280
373
391
N
Indian Reserve
Provincial Highway
Ferry
Kilometres
Miles
Study area


100°
98°
96°
94°
57°
56°
MISSI FALLS
Southern
Indian
Lake
SOUTH INDIAN LAKE
Gauer
Lake
CHURCHILL
RIVER
River
Rat
LEAF RAPIDS
GRANVILLE LAKE
Rat Lake
Baldock Lake
Waskaiowaka Lake
LIMESTONE
RIVER
Stephens
Lake
KETTLE
NELSON
LONG SPRUCE
GILLAM
SPLIT LAKE
Split
Lake
YORK LANDING
ILFORD
KELSEY
Notigi Lake
Wapisu Lake
NOTIGI
NELSON HOUSE
Threepoint Lake
THOMPSON
Wuskwatim Lake
PIKWITONEI
NELSON
RIVER
THICKET PORTAGE

MAP 2

FLOW AND LEVEL

LAKE WINNIPEG REG
AND CHURCHILL RIVER

LEGEND

CLASS	
1	FLOODING DUE TO IMPOUNDMENT
2	MAINTANED NEAR HIGH END OF NATURA LEVEL RANGE DUE TO IMPOUNDMENT
3	FLOODING, ALTERED SEASONAL FLOW DUE TO DIVERSION
4	DECREASED OVERALL FLOW, INCREASE RANGE AND LEVEL RANGE, DEWATERED LAKES DUE TO DIVERSION
5	INCREASED FLOW RANGE AND LEVEL R (with lower minimum summer levels) DUE TO UPSTREAM CONTROLS
6	ALTERED SEASONAL FLOW REGIME DU UPSTREAM CONTROLS
	RESOURCE AREA (Trapline Section) BOU
	CONTROL STRUCTURES
	INDIAN RESERVES
	TOWNS
	ROADS
	RAILROADS
	LAKES, RIVERS

PREPARED BY G. McCULLOUGH, FRESH
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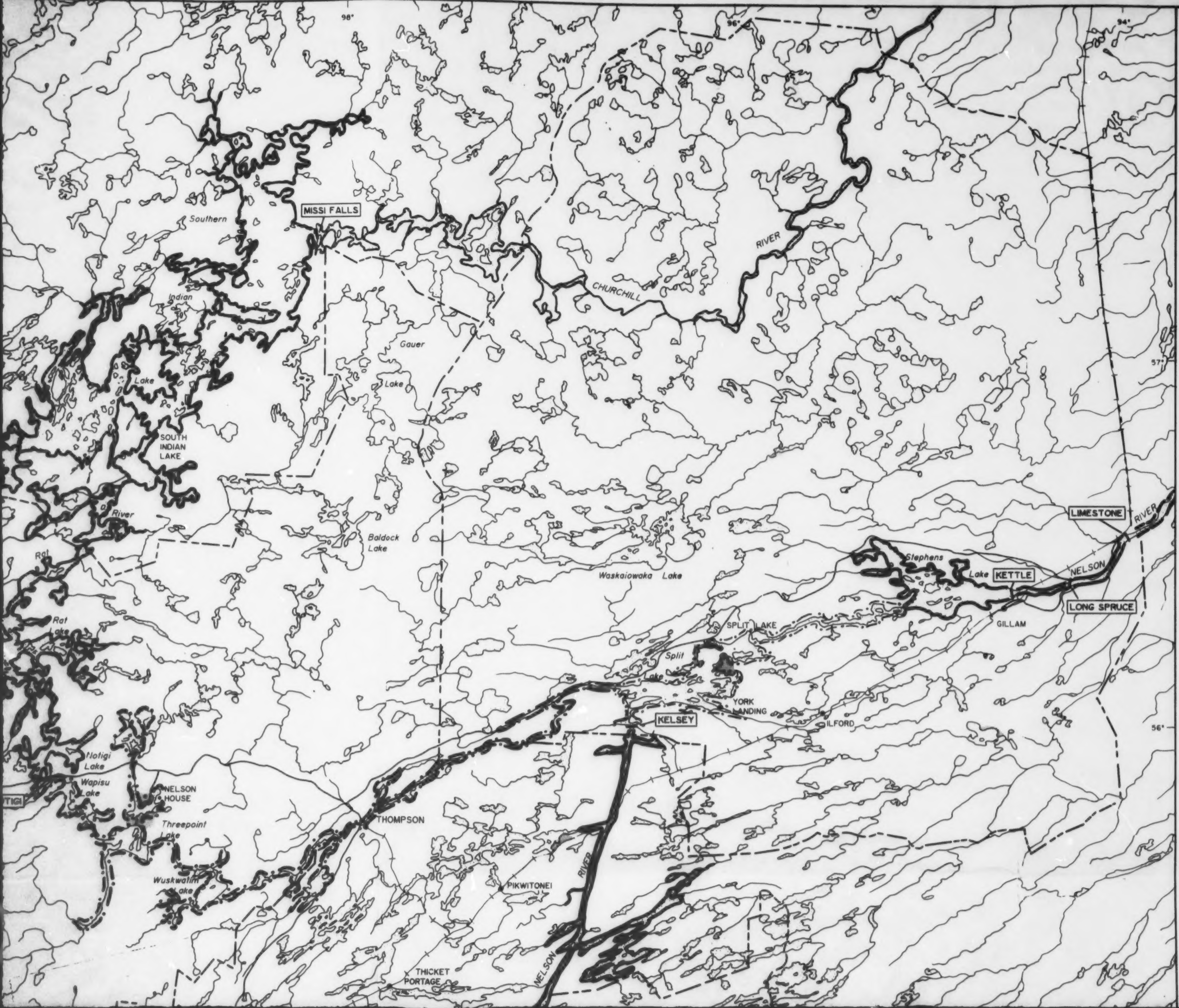
TOWARDS ASSESSING THE EFFECTS O
REGULATION AND CHURCHILL RIVER


98°
96°
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MISSI FALLS
Southern
Indian
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Wapisu Lake
NELSON HOUSE
Threepoint Lake
THOMPSON
Wuskwatim Lake
PIKWITONEI
NELSON
RIVER
THICKET PORTAGE

MAP 2

FLOW AND LEVEL EFFECTS

LAKE WINNIPEG REGULATION AND CHURCHILL RIVER DIVERSION

LEGEND

CLASS		
1	FLOODING DUE TO IMPOUNDMENT	━
2	MAINTANED NEAR HIGH END OF NATURAL LEVEL RANGE DUE TO IMPOUNDMENT	– –
3	FLOODING, ALTERED SEASONAL FLOW REGIME DUE TO DIVERSION	━·━
4	DECREASED OVERALL FLOW, INCREASED FLOW RANGE AND LEVEL RANGE, DEWATERED LAKES DUE TO DIVERSION	~
5	INCREASED FLOW RANGE AND LEVEL RANGE (with lower minimum summer levels) DUE TO UPSTREAM CONTROLS	━ ━
6	ALTERED SEASONAL FLOW REGIME DUE TO UPSTREAM CONTROLS	–·–
	RESOURCE AREA (Trapline Section) BOUNDARY	– – –
	CONTROL STRUCTURES	|
	INDIAN RESERVES	▨
	TOWNS	•
	ROADS	—
	RAILROADS	┼─┤
	LAKES, RIVERS	○

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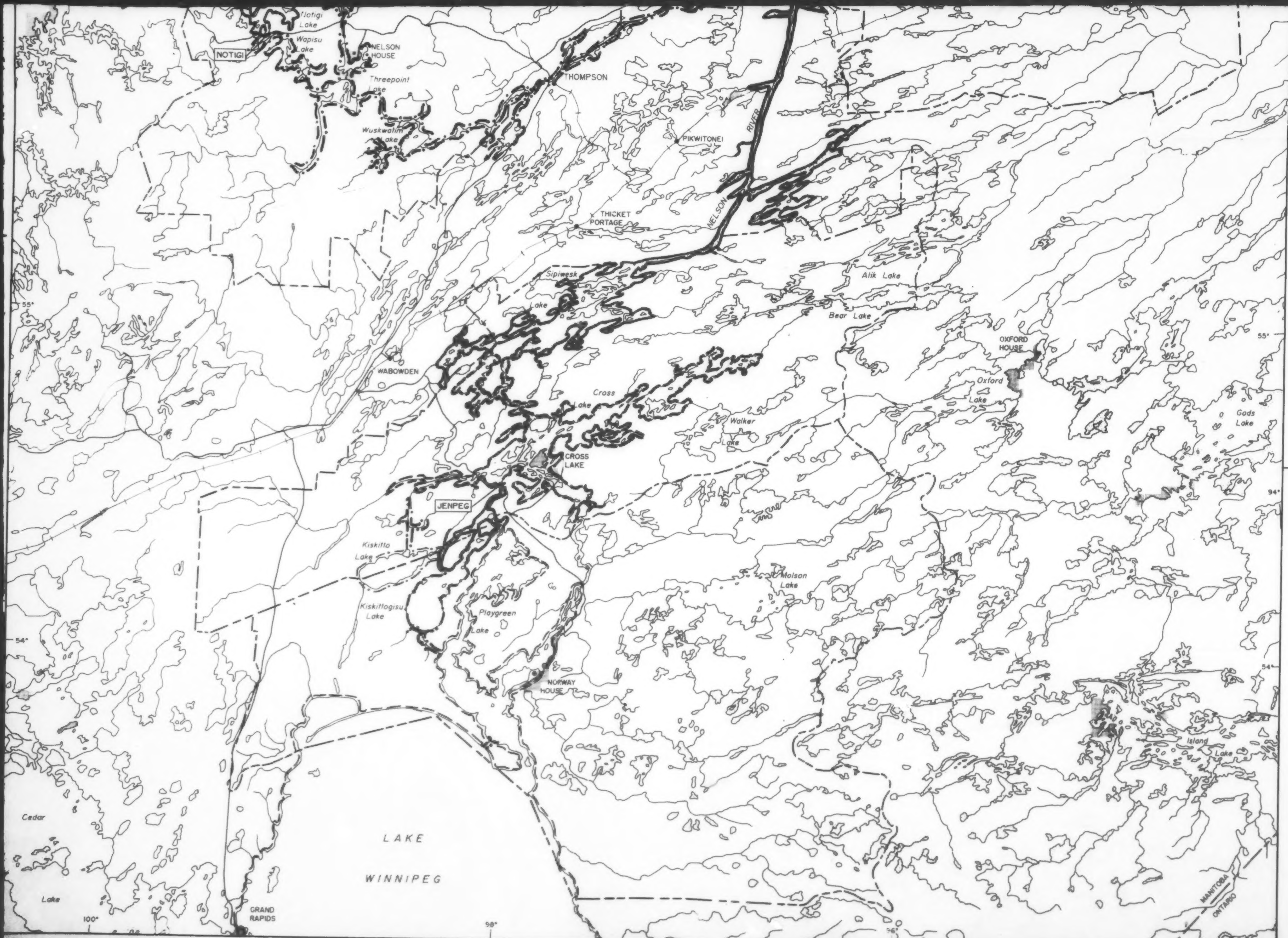
Notigi Lake
NOTIGI
Wapisu Lake
NELSON HOUSE
Threepoint Lake
THOMPSON
Wuskwatim Lake
PIKWITONEI
NELSON RIVER
THICKET PORTAGE
Sipiwesk Lake
Alik Lake
Bear Lake
55°
WABOWDEN
OXFORD HOUSE
Oxford Lake
Cross Lake
Walker Lake
Gods Lake
CROSS LAKE
94°
JENPEG
Kiskitto Lake
Molson Lake
Kiskittogisu Lake
Playgreen Lake
54°
NORWAY HOUSE
Island Lake
Cedar Lake
LAKE WINNIPEG
GRAND RAPIDS
100°
98°
96°
MANITOBA
ONTARIO
10 5 0 10 20
10 5 0 10 20 30 40

LAKES, RIVERS

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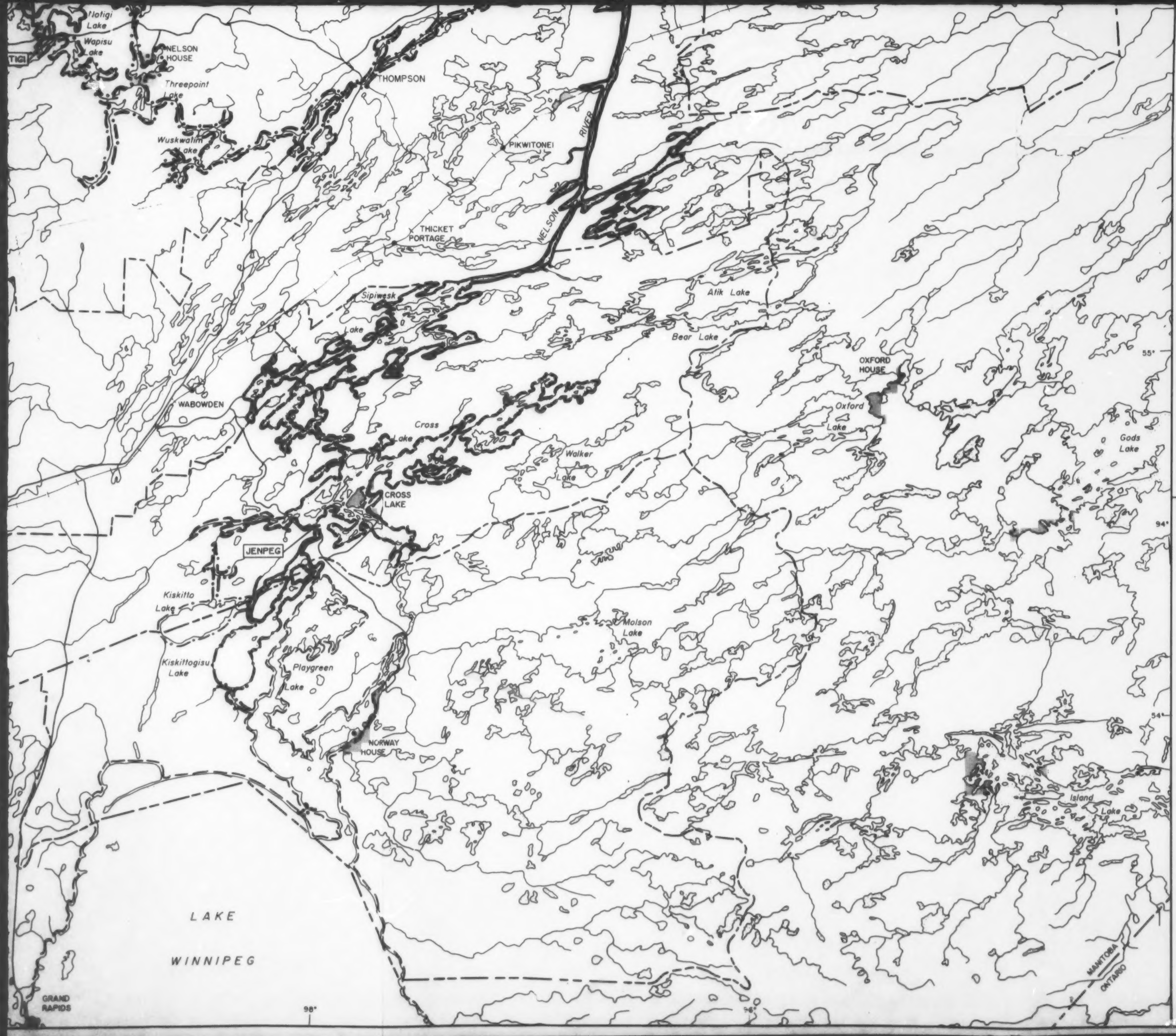
Accompanies Can. Tech. Rep. Fish. & Aq
TOWARDS ASSESSING THE EFFECTS C
REGULATION AND CHURCHILL RIVER D
RESOURCE HARVESTING IN NATIVE CO
NORTHERN MANITOBA. P.J. Usher and M

R.
Churchill
R.
Nelson
LAKE
WINNIPEG
WINNIPEG

INDEX MAP


Notigi Lake
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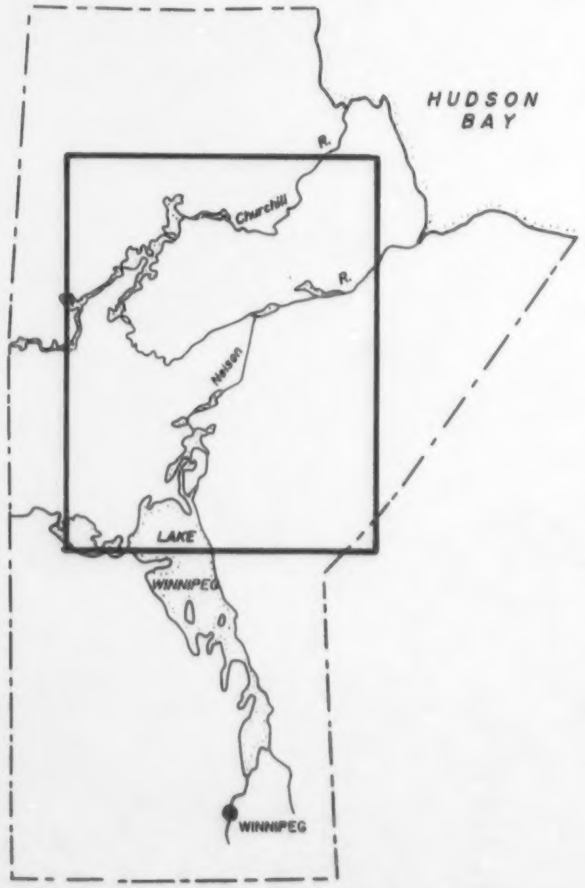
10 5 0 10 20 30 40 Miles
10 5 0 10 20 30 40 50 60 Kilometres


HUDSON BAY
Churchill R.
Nelson R.
LAKE WINNIPEG
WINNIPEG

INDEX MAP